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STEAM-BOILER ECONOMY

A TREATISE ON THE THEORY AND PRACTICE OF FUEL ECONOMY IN THE OPERATION OF STEAM-BOILERS

BY

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SECOND EDITION, REVISED AND ENLARGED; WITH NEW CHAPTERS ON BOILER DESIGN AND CONSTRUCTION, AND BOILER-ROOM APPLIANCES

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PREFACE TO THE SECOND EDITION.

IN the fourteen years since the first edition of this book was issued numerous improvements have been made in boiler practice. Steam pressures have increased, but methods of construction and of caring for boilers have improved to such an extent that there are fewer explosions relative to the number of boilers in use. There is more than twice as much coal burned per day in the Western cities, but the smoke nuisance is decreasing. The increased fuel economy due to the adoption of better methods of burning coal has raised the maximum boiler efficiency obtained in the best practice with soft coal from 76 per cent to 81 per cent, and the efficiency in average practice has probably increased in a greater ratio. Boilers are now driven in electric power stations at double their former rate, with higher fuel economy and with decreased cost of labor and maintenance. The possible saving of money by the operation of boilers by modern, as compared with old methods, is so great that it is now recognized that the boiler plant, rather than the engine room, is the place where money is made or lost, and that it pays to study and to adopt modern methods in the boiler plant, to keep statistics of operation, and to employ intelligent and high-priced labor.

The several elements that have contributed to the improvements in modern practice and the nature of the results obtained from them may be tabulated as follows:

IMPROVEMENTS	RESULTS
Much larger boilers.	Economizing real estate and cost of setting.
Very large combustion chambers.	Burning coal without smoke.
Rapid driving.	Economy in cost of plant.
Coal- and ash-handling machinery.	Dispensing with all labor for shoveling and wheeling coal.

Mechanical stokers.	Feeding coal uniformly, avoiding loss due to opening of doors. Regulating the coal and air supply so as to maintain uniform furnace conditions.
Gas analysis.	Check on the air supply, enabling the operator to adjust the air supply to that required for maximum economy.
Superheaters.	Insuring dry steam and improving engine efficiency.
Draft gauges.	Enabling the operator to know at all times the difference in draft pressure between the ash pit and the furnace and between the furnace and the flue, and to equalize the draft in the several boilers of a plant.
Electric pyrometers.	For finding temperatures at different points in the gas passages, to discover if the baffling is in good order.
Purchase of coal under specifications, analyses and calorimeter tests of coal.	Enabling the purchaser to obtain coal of known quality for a stated price.
Treatment of feed-water.	Diminishing the danger and the loss of economy due to scale, the cost of removal of scale, the time boilers are out of service for cleaning and for repairs, the cost of renewal of tubes and other repairs.
Better construction and higher factors of safety.	Diminishing danger of explosion.
Recording and plotting of boiler performance.	Knowledge of performance under different conditions of operation.
Bonus and premium systems of payment of wages.	Securing maximum efficiency of labor.

In the present edition all of these several improvements are discussed at length. Numerous records of recent tests of different kinds of boilers are given, showing the efficiency that may be obtained with different coals under different conditions of operation.

The author's formula, given in Chapter IX, showing the relation that exists between boiler efficiency, the rate of driving, the air supply, and other variables that have a relation to efficiency, has been developed so as to show the effect of imperfect combustion and of moisture in coal, and a new straight line formula for efficiency, assuming complete combustion, and plotted diagrams made from it has been devised, enabling the user to predict the maximum economy that can be obtained with different rates of driving and different proportions of air supply. New tables of analyses and heating values of American coals are given, and the chapters on Coal Fields of the United States and Heating Value of Coal have been revised.

Two new chapters have been added, one on Boiler Design and Construction, and one on Boiler Attachments and Boiler Room Appliances, which will make the book as a whole more useful to students.

New York, July 1, 1915.

Extract from the Preface to the First Edition, 1901.

In the year 1875 the author made his first evaporative test of a steam-boiler. It was the Pierce rotating boiler, which was tested at the Centennial Exhibition the following year. It had certain peculiarities of design which were supposed by the inventor to make it more efficient than any other boiler then on the market. The testing of this boiler and of two others during the same year led the author to study seriously the problem: "On what conditions does the fuel economy of a steam-boiler depend?" For three years, 1882-5, he was in the employ of the Babcock & Wilcox Co., and it was part of his work to make evaporative tests of the boilers made by that company, and of other kinds of boilers for comparison, in different sections of the country, and with all kinds of coal. In connection with his office practice from 1890 to the present time, he has had occasion to make nearly a hundred boiler-tests, with different boilers, fuels, and furnaces. Besides having this practical experience, together with the habit of studying

critically the result of each test for the purpose of drawing conclusions from it, the author has been a constant student of the literature of the subjects of boiler-testing and fuel economy which from time to time appears in the transactions of engineering societies, in the technical press, in trade catalogues, and in books. He has thus been enabled to compare theory with practice.

Many books have been written on the subjects of boilers, furnaces, and fuels, but in none of them does it seem that the problem of steam-boiler economy has been treated with the thoroughness which its importance deserves. Most of the treatises on boilers devote the greater part of their space to details of construction, and only a small space to the subject of fuel economy. There appears to be a demand for a new book which shall treat solely of steam-boiler economy and of subjects related thereto. To supply such a demand this book is offered.

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STEAM-BOILER ECONOMY.

CHAPTER I.

PRINCIPLES AND DEFINITIONS.

A Steam-boiler is a vessel in which, by the agency of heat derived from the combustion of fuel, water is converted into steam.

The study of the operation of a steam-boiler includes the consideration of the following subjects:

1. The fuel, its kind, quality, and chemical composition.

2. The air supplied to the fuel to effect its combustion or rapid oxidation, also the moisture in the air.

3. The furnace in which the combustion, more or less complete, takes place; its construction and its fuel-burning capacity.

4. The loss of unburned fuel through the grate-bars of the furnace, or in the ashes withdrawn from it.

5. The heat generated by the combustion; its quantity; the temperature attained in and beyond the furnace; and the efficiency of the combustion, or the ratio which the quantity of heat actually generated bears to that which might be generated with perfect combustion.

6. The gaseous products of combustion, and their dilution by an excessive supply of air.

7. The transfer of heat from the fire, and from the hot gases generated by the combustion, through the shell or tubes of the boiler into the water, and the conditions which increase or diminish the rate and the effectiveness of the transfer.

8. The loss of heat due to the escape of hot gases into the flue or chimney.

9. The loss of heat due to radiation from the external surfaces of the furnace and boiler.

10. The properties of water and steam at different temperatures.

11. The capacity of the boiler, or the quantity of water it is capable of converting into steam under certain given or assumed conditions.

12. The efficiency of the boiler, or the ratio of the heat absorbed by the boiler to the heat which would be generated by the complete combustion of so much of the fuel as is actually burned.

13. The efficiency of the boiler and furnace combined, or the ratio of the heat absorbed by the boiler to the heat which would be generated by complete combustion of all the fuel used, including that lost through the grates and withdrawn in the ashes.

The consideration of each one of the several items specified above is necessary to a thorough understanding of the operation and the fuel economy of a steam-boiler, and each will be discussed at length in succeeding chapters of this book.

The general subject of steam-boiler economy, however, includes other subjects than those relating to fuel economy, such as the construction of the boiler in its relation to strength, durability, repairs, facility of cleaning, space occupied, first cost, cost of labor for its operation; etc. These will also be treated of in their proper place.

Heat is a form of energy in bodies, supposed to consist of molecular vibration. Its nature, like that of gravity and electricity, is not clearly understood, but its effects may be perceived and measured. Its intensity in any body may be measured in degrees of temperature by a thermometer or pyrometer. Its quantity may be measured in heat-units. When two bodies, one hotter or at a higher temperature than the other, are placed in contact, there is a flow of heat from the hotter into the cooler body, tending to equalize their temperature, and the quantity of heat thus transferred may be measured or estimated if the nature or composition, the weight, and the temperature of the two bodies are known. One or both the bodies may experience a *change of state* by reason of the transfer of heat. Thus if a piece of ice be plunged into a vessel containing steam, the flow of heat from the steam will condense it into water, and the flow of heat into the ice will cause the latter to melt and be changed also into water.

Temperature, or intensity of heat, is measured in degrees, by a thermometer or pyrometer. Certain fixed or standard temperatures are identified by certain phenomena of the change of state of certain bodies. The two most commonly used standard temperatures are: (1) that of melting ice, zero on the Centigrade thermometric scale or 32° on the Fahrenheit scale, and (2) that of the boiling-point of pure

water at the mean atmospheric pressure of 14.7 lbs. per square inch, viz., 100° on the Centigrade scale or 212° on the Fahrenheit scale. The Fahrenheit scale is most commonly used in England and the United States. If the range of temperature between the freezing and the boiling-points of water be divided into 180 equal parts, we obtain the scale of degrees of the Fahrenheit thermometer, which scale may be extended indefinitely downwards and upwards to measure the lowest and the highest temperatures found in the arts. For scientific measurements of great accuracy and through a wide range degrees of temperature may be measured by the air-thermometer, in which the recorded degree of temperature is proportional to the product of the pressure and volume of a given weight of air.* For all ordinary purposes the mercury thermometer is available between the range of — 40° and 600° F., and mercury thermometers with compressed nitrogen in the tube above the mercury may be used for temperatures as high as 900° or 1000° F. For higher temperatures, up to 3000° F., the Uehling and Steinbart air pyrometer, the Chatelier and the Bristol electric pyrometers, and the Fèry radiation pyrometer are available. For obtaining the temperature of chimney-gases, from 300° to 1200°, metallic pyrometers may be used, but their indications are apt to be inaccurate.

The temperatures commonly observed in steam-boiler practice are, on the Fahrenheit scale:

1. The temperature of the feed-water, from 32° to 300° and upwards.

2. The temperature of the steam, from 212° to 400° (corresponding to saturated steam of 250 lbs. per sq. in. absolute pressure) and upwards (500° or over for highly superheated steam).

3. The temperature in the furnace, from 1000° to 3000° or upwards.

4. The temperature of the escaping flue-gases, from 300° to 1200° and upwards.

5. Temperatures of the gases of combustion, taken at points in the gas-passages through the boiler intermediate between the furnace and the flue.

A Heat-unit, or British Thermal Unit (B.T.U.), is the quantity of heat required to raise the temperature of one pound of pure water

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* Consult Rankine, Steam-engine, p. 226; Kent's Mech. Engrs. Pocket-book, 8th edition, p. 530; Trans. A. S. M. E., vol. vi. p. 282.

one degree Fahrenheit, or, more accurately, 1/180 of the heat required to raise it from 32° to 212° F.

The quantity of heat required to raise the temperature of one pound of water 1° F. varies very slightly with the temperature, being nearly constant below 100° F. and increasing at higher temperatures, so that to raise its temperature from 32° to 100° requires 67.97 instead of 68 B.T.U., and from 100° to 300°, 201.6 instead of 200 B.T.U.

The Unit of Evaporation (U.E.) is the quantity of heat required to convert one pound of water at 212° into steam of the same temperature. It is equivalent to 970.4 B.T.U.

Latent Heat is the quantity of heat which apparently disappears (or becomes latent or hidden, and therefore not measurable by a thermometer) when a body changes its state from solid to liquid or from liquid to gaseous, while the temperature remains constant. Thus when a pound of ice at 32° is converted into water at the same temperature, 144 B.T.U. becomes latent, and when a pound of water at 212° is converted into steam at 212°, 970.4 B.T.U. (or one U.E.) becomes latent.

When a body changes its state from the gaseous to the liquid form, or from the liquid to the solid form, the heat which was latent is given off and becomes sensible heat. Thus a pound of steam at 212° in condensing to water at 212° transfers 970.4 B.T.U. to surrounding bodies, raising their temperature, and a pound of water at 32° freezing into ice at the same temperature will give off 144 B.T.U. to the surrounding atmosphere.

Specific Heat is a figure representing the quantity of heat, expressed in thermal units, required to raise the temperature of one pound of any given substance one degree; or it is the ratio of the quantity of heat required to raise the temperature of a given weight of the substance one degree to the quantity required to raise the temperature of the same weight of water from 62° to 63° F. The specific heat of water at 62° F. being taken at unity, that of all other known substances, except hydrogen, is less than unity.

One of the methods of determining the specific heat of a body is the method by mixture, described as follows:

The body whose specific heat is to be determined is raised to a known temperature, and is then immersed in a mass of liquid of which the weight, specific heat, and temperature are known. When

both the body and the liquid have attained the same temperature, this is carefully ascertained.

Now the quantity of heat lost by the body is the same as the quantity of heat absorbed by the liquid.

Let c, w, and t be the specific heat, weight, and temperature of the hot body, and c', w', and t' of the liquid. Let T be the temperature the mixture assumes.

Then, by the definition of specific heat, $c \times w \times (t - T)$ = heat-units lost by the hot body, and $c' \times w' \times (T - t')$ = heat-units gained by the cold liquid. If there is no heat lost by radiation or conduction, these must be equal, and

$$cw(t - T) = c'w'(T - t') \quad \text{or} \quad c = \frac{c'w'(T - t')}{w(t - T)}.$$

The specific heats of several different substances at ordinary atmospheric temperatures are given below:

SOLIDS.

Copper	0.0951	Aluminum	0.2185
Glass	0.1937	Charcoal	0.2410
Iron, cast	0.1298	Coal	0.20 to 0.24
Iron, wrought	0.1138	Coke	0.203
Steel, soft	0.1165	Brickwork and masonry	about 0.20
Platinum	0.0324	Wood	about 0.32

LIQUIDS.

Water	1.0000	Mercury	0.0333

GASES.

	At Constant Pressure.	At Constant Volume.
Steam, superheated *	0.4805	0.346
Air	0.2375	0.1685
Oxygen	0.2175	0.1551
Hydrogen	3.4090	2.4122
Nitrogen	0.2438	0.1727
Carbon monoxide, CO	0.2479	0.1758
Carbon dioxide, CO_2	0.217	0.1710
Marsh-gas (methane), CH_4	0.5929	0.4683
Olefiant gas (ethylene), C_2H_4	0.404	0.332
Blast-furnace gas	0.228	
Gases in chimneys of steam-boilers (approx.)	0.240	

* These figures are from Regnault' sexperiments. More recent determinations show that the specific heat of superheated steam varies with the pressure and temperature. See M.E. Pocket-book, p. 838.

The specific heat of a gaseous mixture, such as that of a chimney-gas, is found by multiplying the percentage of each of the constituent gases by the specific heat of that gas and dividing the sum of the products by 100. Thus for a gas whose composition is CO_2, 12; CO, 0.5; O, 9.5; N, 78, we have

CO_2	12×0.217	$= 2.604$
CO	0.5×0.248	$= 0.124$
O	9.5×0.2375	$= 2.256$
N	78×0.2438	$= 19.016$
	100.0	24.000

Whence the specific heat is

$$24.0 \div 100 = 0.240.$$

The specific heats of all substances in the solid or liquid state increase slowly as the temperature rises. Experiments by Mallard and Le Chatelier indicate a continuous increase in the specific heat of CO_2, steam, and other gases with rise of temperature. The variation is inappreciable at 212° F., but increases rapidly at high temperatures. In the absence of data of specific heats of gases at high temperatures, the figures given in the above tables are generally used in calculations relating to gases of combustion, although their use may lead to errors of unknown magnitude in the results. (See page 340.)

The following figures, showing increase of specific heat of metals with rise of temperature, are sometimes used in pyrometric calculations:

Platinum, 22° to 440° F., 0.0332, increasing 0.000305 for each 100° F. above 440°.

Copper, 32° to 212°	0.094
" 32° to 572°	0.1013
Wrought iron, 32° to 212°	0.1138
" 32° to 500°	0.1228
" 32° to 1300°	0.1601
" 32° to 1500°	0.1698
" 32° to 2700°	0.1666

The Quantity of Heat in a body, in British thermal units, measured above a certain temperature taken as standard, usually 32° F., is the product of its weight, its average specific heat between the limits of temperature considered, and the difference between its temperature and the standard temperature. Thus the quality of heat above 32° in a piece of wrought iron weighing 10 lbs., at a temperature of 212°, is $10 \times .1138 \times (212 - 32) = 204.84$ B.T.U.

This statement is true, however, only when the body does not change its state between the standard temperature and the higher temperature. When the body changes its state, its latent heat must be considered. Thus the heat above 32° in a pound of steam is the sum of

Heat required to raise its temperature from 32° to 212°	180.0	B.T.U.
Latent heat of evaporation at 212°	970.4	"
Total	1150.4	"

The quantity of heat in a pound of saturated steam at 320° F. (75.3 lbs. gauge pressure per sq. in.) is

Heat (above 32°) in water at 320°	290.5	B.T.U.
Latent heat of evaporation at 320°	893.9	"
Total	1184.4	"

When the steam is superheated, the quantity of heat required for superheating must be added. Thus if the steam of 75.3 lbs. gauge pressure, whose temperature when saturated is 320°, be superheated, while its pressure remains constant, to 420°, the increase of 100° of temperature will require, since the specific heat of superheated steam at that pressure and between 320° and 420° is about 0.526, an addition of 52.6 B.T.U., making the total heat $1184.4 + 52.6 = 1237$ B.T.U. The properties of steam will be discussed further in another chapter.

Heat of Combustion.—Every combustible chemical element, such as carbon, hydrogen, and sulphur, and every gaseous fuel of definite chemical composition, containing two or more elements, such as carbon monoxide (CO) and methane (marsh-gas, CH_4), when completely burned in oxygen or in air generates a definite quantity of heat per pound of the combustible, which quantity may be ascertained with a close approximation to accuracy by means of an instrument known as a fuel calorimeter. The exact determination of the heat of combustion, or calorific value, of any combustible requires a very delicate apparatus, a high degree of skill on the part of the operator, and an allowance for certain unavoidable errors, such as loss by radiation, so that the calorific values of different combustibles as reported by different authorities show a slight variation. Thus the heating value of carbon is 14,544 B.T.U. according to Favre and Silbermann, and 14,647 B.T.U. according to Berthelot. That of hydrogen is 62,032 B.T.U. according to Favre and Silbermann, and 61,816 B.T.U. accord-

ing to Thomsen. The round figures of 14,600 B.T.U. for carbon (burned to carbon dioxide) and 62,000 B.T.U. for hydrogen (burned to steam and the steam condensed to liquid water) are generally used in calculations relating to steam-boiler practice.

The heating value of any fuel, such as coal, consisting of a mixture of combustible and non-combustible substances may be directly determined by means of a calorimeter, or it may be calculated from its ultimate chemical analysis by Dulong's formula, which is:

$$\text{Heating value} = \frac{1}{100} \times \left[14{,}600C + 62{,}000\left(H - \frac{O}{8}\right) + 4000S\right],$$

in which C, H, O, and S are the percentages of carbon, hydrogen, oxygen, and sulphur in the coal, as determined by analysis.

Combustion of Fuel.—Combustion may be perfect or imperfect, depending upon the supply of air in the furnace and upon other conditions which will be discussed later. When the combustion is perfect the whole of the carbon in the fuel is burned to carbon dioxide, CO_2, each pound generating 14,600 B.T.U., and the whole of the hydrogen is burned to steam, or vapor of water, H_2O, each pound generating 62,000 B.T.U. Part of the heat of the combustion of hydrogen is absorbed in the latent heat of evaporation of the 9 lbs. of steam formed by the combustion of 1 lb. of hydrogen, and another part in superheating, to the temperature of the furnace, this steam, and also the steam that may be derived from moisture in the coal or in the air supplied to the furnace.

When the combustion is imperfect part of the carbon may be burned only to carbon monoxide, CO, generating only 4450 B.T.U. per pound; or part of the carbon which has been burned on the grate to CO_2 may be "unburned," being converted into CO on passing through a bed of red-hot coke, absorbing carbon therefrom by the chemical reaction $CO_2 + C = 2CO$, a cooling process, absorbing 10,150 B.T.U. per pound of the C originally burned to CO_2. Also, in imperfect combustion some of the hydrogen, together with the carbon with which it is combined in the coal, forming the "volatile matter," may be only distilled from the coal and not burned, or the hydrogen only in this volatile matter may be burned, leaving the carbon, in the form of soot or smoke, to be carried off in the gases passing out of the furnace. All the products of imperfect combustion, the carbon monoxide, the hydrocarbon gases distilled from the

coal, and the soot or smoke, may afterwards be burned if they are carried into a very hot chamber, where they are thoroughly mixed with a sufficient supply of highly heated air.

How Smoke may be Burned.—This last statement is contrary to that made by Charles Wye Williams in his treatise "On the Combustion of Coal and the Prevention of Smoke," first printed about sixty years ago, and copied extensively by later writers, viz., that "When smoke is once produced in a furnace or flue, it is as impossible to burn it or convert it to heating purposes as it would be to convert the smoke issuing from the flame of a candle to the purposes of heat or light." The error of the statement made by Mr. Williams can be easily shown by a simple experiment which has been made by the author. A short piece of candle was placed inside of a tall, narrow tin cylinder. The deficient supply of air the candle thus received caused it to give off a column of black smoke. This was caused to pass into the central-draft tube of a "Rochester" kerosene lamp, and as it passed up into the flame of the lamp it was completely burned, not a trace of smoke being visible in the lamp-chimney. The experiment was also made with a still larger column of smoke, produced by burning paper under the lamp, with the same result.

Flame is a mass of intensely heated combustible gas. It is not necessarily gas in a state of combustion, for combustion cannot take place without access of air, and flame may exist, as in passing through a furnace or flue, where there is no supply of air to burn the gas. If the flame in passing through a tube becomes cooled below a bright red heat, the gas will not burn when it escapes and comes in contact with cool air, but will be chilled and pass off as unburned gas and smoke.

The flame of pure hydrogen gas is almost invisible, but visibility and color may be given to it by the presence of other substances; thus carbon will make it white, copper green, cyanogen purple, and sodium yellow.

The white color of the flame of hydrocarbon gas, such as that from a candle or that of a kerosene lamp, is due to intensely heated particles of carbon. If the flame is caused to impinge on a cold surface, some of these particles will be deposited as soot.

Visible flame is evidence of imperfect combustion or non-combustion. The product of the perfect combustion of carbon is invisible carbon dioxide gas, and that of hydrogen is invisible vapor of water.

Take a lighted central-draft kerosene lamp and adjust the wick to such a point that the lamp gives a rather short and clear white light

without a trace of smoke. Now, without altering the adjustment of the wick, gradually obstruct the opening at the bottom of the central-draft-tube and observe the result. The flame grows longer and its whiteness changes to yellow and then to red. It begins to smoke, and finally when the supply of air is nearly shut off the flame has risen to nearly the top of the chimney and a dense column of black smoke and soot is given off. We learn from this experiment that with the same consumption of fuel, i.e., the oil supplied by the wick, the flame may be short and intensely hot, or very long, of a low temperature, smoky and sooty. While the flame is lengthening and before it becomes smoky the combustion may be complete, but it is not effected in as short a space as it was with the original supply of air. For a given supply of fuel a short flame means rapid and complete combustion, a longer flame delayed combustion, and a very long flame imperfect combustion. If midway in the flame of medium length a cool surface be interposed, the temperature of the flame will be lowered, the combustion will be rendered imperfect, and smoke and soot will be produced.

The principles learned from these simple experiments with the flame of a lamp are of great importance in connection with the study of the action of steam-boiler furnaces.

A Transfer of Heat from the burning fuel and from the hot gases produced by its combustion into the water contained in a steam-boiler takes place through the metal plates and tubes of the boiler in two ways: (1) by radiation directly from the fire and from the hot particles of carbon in the flame, and (2) by contact of the hot gases with the metal of the boiler. The laws of these two methods of transfer are as yet imperfectly understood, and there is a great lack of accurate scientific data concerning them. The experimental determination of these data is a matter of extreme difficulty, on account of the number of variable conditions attending the experiments. Such conditions are: the extent of surface exposed to direct radiation; the temperature of the radiating surfaces, the resistance to radiation of metal plates in different conditions, more or less coated with scale and soot; the manner in which the heated gases impinge upon the shell and tubes; the triple resistance to transfer of heat from the gases to the water, viz., the resistances of the external and internal surfaces of the metal, varying with their condition, and the resistance of the metal between these surfaces, varying with the nature of the metal and its thickness; the influence which the temperature of the gases on one side of the

plate and tubes, steadily decreasing as they pass from the furnace to the flue, and the temperature of the water on the other, sensibly constant, have upon the rate of transfer of heat through the metal and its exterior and interior surfaces. Notwithstanding, however, the lack of accurate knowledge concerning the influence of these several variables on the transfer of heat in steam-boilers, enough is known to enable us to deduce some broad general laws, and to express some of them in empirical formulæ, so that boilers may intelligently be designed to fill given requirements, and so that the probable performance of any boiler and furnace may be predicted from a study of its design and dimensions, when the character of the fuel is known, within limits of error sufficiently narrow for practical purposes.

The Capacity of a Boiler is its capacity for producing steam. It may be expressed in the number of heat-units absorbed by the boiler in a given time, such as one second, or in the number of pounds of water converted into steam in an hour.

"Equivalent" Evaporation.—Since the latter number will depend upon the temperature of the feed-water and upon the pressure or temperature of the steam, it is customary to express the capacity in terms of what is called "equivalent evaporation," that is, reducing the number of pounds of steam actually generated at a given or observed pressure from feed-water of an observed temperature, into the equivalent evaporation per hour from feed-water of 212° into steam at the same temperature, or, as it is commonly expressed, "equivalent evaporation per hour from and at 212°."

The evaporation of a pound of water from and at 212° being the "unit of evaporation" (U.E.), equal to 970.4 B.T.U., the capacity of a boiler may be stated as so many U. E. per hour.

Boiler Horse-power.—Another convenient method of expressing the capacity of a boiler is in terms of "Boiler Horse-power," a boiler horse-power being equal, according to a commonly accepted convention, to 34½ U.E. per hour, or 34½ lbs. of water evaporated from and at 212° per hour. This latter is the usual method of expressing the capacity of stationary boilers in the United States. It is not used for marine or locomotive boilers.

A boiler rated at 100 H.P. would therefore be rated also at a capacity of 3450 lbs. of water from and at 212° per hour, or at 3,347,880 B.T.U. per hour, or 930 B.T.U. per second. The B.T.U. rating is not used in practice, as it is not so convenient as the other methods of rating.

It is to be noted that the "rating" of a boiler as 100 H.P. may be very different from the actual capacity it may show under a given set of conditions. The "rating" is supposed to be its average capacity under easy conditions of driving, with fairly good fuel, and with ordinary draft. Two boilers exactly alike in all respects may both be rated at 100 H.P., and one of them with excellent fuel and forced draft may be actually developing 200 H.P., while the other, with poor fuel or insufficient draft or both, may not be capable of developing over 75 H.P.

The Efficiency of a Boiler may mean: 1. The ratio of the heat absorbed by it to the heat actually generated in the furnace; 2. The ratio of the heat absorbed by it to the heating value of the combustible actually burned (whether thoroughly or not); 3. The ratio of the heat absorbed by it to the heating value of the fuel supplied to the furnace, whether all the fuel is burned or not (some of the fuel may fall through the grates or be withdrawn with the ashes, and not be burned). The first of these efficiencies is not used in practice, for the reason that there is no convenient way of estimating the amount of heat actually generated in the furnace, or of determining what portion of the fuel is imperfectly burned. The second and third are commonly used and are thus defined:

$$\text{Efficiency of boiler} = \frac{\text{Heat absorbed per lb. combustible burned}}{\text{Heating value of 1 lb. combustible}}.$$

$$\left.\begin{array}{r}\text{Efficiency of boiler,}\\ \text{furnace, and grate}\end{array}\right\} = \frac{\text{Heat absorbed per lb. coal fired}}{\text{Heating value of 1 lb. coal}}.$$

The meaning of the word "combustible" in the above definitions is that portion of the total fuel supplied to the furnace which remains after deducting its moisture (determined by a test of a sample) and the total amount of ash and refuse (including unburned coal) withdrawn from the furnace, through the grates or otherwise. In other words it is the sum of the fixed carbon and the volatile combustible matter, or the "coal dry and free from ash."

The Operation of a Steam-boiler.—The several events that take place in the operation of an ordinary steam-boiler may be briefly described as follows: Consider that the furnace is already heated, a hot fire of partially burned coal or coke lying on the grate, and that the boiler is delivering steam as usual. A few shovelfuls of fresh coal are evenly spread over the bed of hot coal, to replenish the fire. The first thing that then takes place is the evaporation of the moisture

contained in the fresh coal. This absorbs heat from the fire, cooling it for a short time. If the fresh coal is of small size, it partly fills the interstices between the pieces of hot coal, and thereby checks the draft and diminishes the supply of air which enters through the grate. The formation of the steam by the evaporation of the moisture in the fuel, together with the reduction of the air-supply, may cause two chemical actions to take place which are in the nature of "decomposition" or the reverse of combustion or rapid oxidation, both of which are detrimental to the most economical operation of the boiler. The first is the decomposition of the carbon dioxide, formed by the union of the oxygen of the air with the carbon of the hot coal lying next to the grate bars, into carbon monoxide, by the reaction $CO_2 + C = 2CO$, which takes place when carbon dioxide is passed through a bed of very hot coal or coke, the supply of air being deficient. The second is the decomposition of a portion of the steam produced by the evaporation of the moisture in the coal, by the reaction $H_2O + C = 2H + CO$, which takes place when steam is brought in contact with very hot carbon. Both of these reactions or decompositions are cooling processes, absorbing heat from the fire, and they therefore diminish the rate of transfer of heat through the heating surface of the boiler. Moreover, they both rob the bed of fuel of some of its carbon, converting it into combustible gases which may escape unburned, thus causing a loss of heat. Fortunately the length of time during which these reactions, unfavorable to economy, take place is not long when the firing is done carefully, and the fresh coal is fired only in small quantities at a time.

After the moisture is driven off from the coal the volatile matter begins to be distilled, and this continues until the fresh coal has attained a red heat. When the amount of this volatile matter is small, when the air-supply is sufficient, and when the furnace is at a high temperature, it may all be completely burned before it passes out of the furnace; but if it is distilled in large volume and is not brought into intimate mixture with air at a temperature high enough to maintain ignition, more or less of it will escape unburned.

After the volatile matter has been driven off, the combustion of the remainder of the coal or coke is completed. If the relation of the thickness of the bed of coal on the grate to the force of the draft is such that only so much air passes through the grate as will cause the complete combustion of the carbon to CO_2, the temperature of the furnace will be very high, a most favorable condition for economy of

the boiler. If the force of the draft be excessive, in relation to the resistance of the grate and the fuel upon it to the passage of air, or if the bed of coal be too thin, an excessive supply of air will pass into the furnace, lowering its temperature and making conditions unfavorable to economy. If, on the other hand, the thickness of the bed of coal is too great in its relation to the force of the draft, or the draft is insufficient, the air supply to the furnace will not be enough to secure complete combustion, part of the carbon will be burned only to CO, and the furnace temperature will be low. In this case there is thus a twofold loss of economy; first, that due to direct loss of heat-units by imperfect combustion; and second, that due to low furnace temperature, which lessens the rate of transfer of heat into the boiler.

While the coal is being burned as above described it generates a quantity of heat, more or less according to the degree of completeness of combustion, at a rate varying from one instant to another as the conditions vary, the coal giving off moisture at one period, distilling its volatile matter at another, and having its carbon burned more or less perfectly at another. The temperature of the furnace also varies as these conditions vary, and with it the rate of transfer of heat into the boiler both by radiation and by conduction.

A portion of the heat generated in the furnace being radiated directly from it into the boiler, and a very small portion escaping by radiation through the walls of the furnace (if it is not enclosed in the boiler itself, as in internally fired boilers), the remainder of the heat passes out of the furnace in the heated gases of combustion. These give up to the boiler a portion of their heat as they pass along the heating surfaces, and carry what remains into the flue leading to the economizer or to the chimney, as the case may be. How much of this heat shall be absorbed by the boiler and how much shall pass into the chimney depends upon a number of variable conditions which will be discussed later.

Efficiency of the Heating Surface.—The two principal sources of loss of heat in the ordinary operation of a steam-boiler are: 1. The loss due to imperfect combustion; 2. The loss of heat in the chimney-gases.

If H_1 represents the heat-units in 1 lb. of the gases of combustion in the furnace, and H_2 the heat-units in the same quantity of the same gases as they leave the boiler, the efficiency of the heating surface is represented by the equation

$$E = \frac{H_1 - H_2}{H_1}. \quad \quad (1)$$

If T_1 represents the temperature of the gases in the furnace, and T_2 their temperature as they leave the boiler, the efficiency is also represented by the equation

$$E = \frac{T_1 - T_2}{T_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

on the asumption that the specific heat of the gases is the same at each of the two temperatures. In these equations H_1, H_2, T_1, and T_2 are taken as measured from the temperature of the air supplied to the furnace.

From equation (2) we learn that the efficiency of the heating surface may be increased either by increasing T_1 or by decreasing T_2 or by both. Therefore high efficiency depends both on high furnace temperature and on low chimney temperature. How to increase the furnace temperature, and how, with increased furnace temperature, to decrease the chimney temperature, are the principal things to be learned in regard to the fuel economy of steam-boilers.

The efficiency of the heating surface corresponding to different temperatures T_1 and T_2 is shown in the following table:

$T_1 =$	2500°	2000°	1500°	1000°
	Efficiency, per cent.			
$T_2 =$ 300°	88	85	80	70
400°	84	80	73.3	60
500°	80	75	66.7	50
600°	76	70	60	40
700°	72	65	53.3	30
800°	68	60	46.7	20
900°	64	55	40	10
1000°	60	50	33.3	0

The highest figure of efficiency in the above table, 88%, it is scarcely possible to realize in practice except under unusual conditions, such as the supplying of the furnace with hot air heated by the utilization of some of the heat of the escaping chimney-gases. The lowest figure, 0%, represents an impossible condition, that of no transfer of heat from the gases into the boiler.

The efficiency commonly obtained in practice in the Western States with bituminous coals burned in ordinary furnaces is not over 60 per cent, and is often less than 50 per cent. Probably 55 per cent is a fair average. The highest efficiency obtainable under the best conditions, with mechanical stokers and with furnaces adapted to burn the volatile matter of the coal, is about 80 per cent. The difference, 25 per cent

$\div$ 80 per cent = 31.2 per cent, is the margin for saving. If only half of this saving, or 15.6 per cent, can be made, and this is easily possible by the introduction of improved methods of burning Western coals, the reduction of the cost of coal used for steam purposes, were these improvements generally adopted, would amount to many millions of dollars a year. This is the most important improvement that can be made in existing American boiler practice.

The principles briefly outlined in this chapter form the basis of the theory of the economy of fuel in steam-boilers. They will all be considered in greater detail, with reference to experimental data, in succeeding chapters.

CHAPTER II.

FUEL AND COMBUSTION.

Chemistry of Fuel and of Combustion.—The four principal chemical elements found in fuel and in the air used for its combustion are carbon, hydrogen, oxygen, and nitrogen. The chemical symbols and the atomic weights of these four elements are respectively C, 12; H, 1; O, 16; N, 14. The atomic weights, or combining numbers, are the relative proportions by weight in which the elements always combine with each other to form definite chemical compounds. Some of these compounds are the following:

	Parts by Weight.
Water, H_2O	$2H + 16O = 18H_2O$
Carbon monoxide, CO	$12C + 16O = 28CO$
Carbon dioxide, CO_2	$12C + 32O = 44CO_2$
Methane, CH_4	$12C + 4H = 16CH_4$

The names of the last three compounds are those used in modern works on chemistry. Their older names are: CO, carbonic oxide; CO_2, carbonic acid; CH_4, marsh-gas, or light carburetted hydrogen.

Air is not a chemical compound, but a mixture of oxygen and nitrogen.

Water-gas (pure), $2H + CO$, is a mixture of two parts hydrogen and 28 parts carbon monoxide.

Carbon is found in the pure and solid state in the diamond, in charcoal, and in graphite. Combined with hydrogen it is found in various oils, tars, and gases. Combined with hydrogen and oxygen it is found in the whole range of vegetable products. It is the principal constituent of coal and of most other fuels, whether solid, liquid, or gaseous.

Hydrogen is a very light combustible gas, of only about $\frac{1}{14}$ of the density of air. It may be produced in its pure gaseous state by the electrical or chemical decomposition of water. It is also formed, mixed with carbon monoxide, when steam is passed through a body of white-hot carbon, the chemical reaction being thus expressed:

$$H_2O + C = 2H + CO.$$
$$2 + 16 + 12 = 2 + 28 \text{ parts by weight.}$$
$$18 \text{ parts steam} + 12 \text{ parts carbon} = 30 \text{ parts water gas.}$$

Hydrogen is a constituent of most fuels, solid, liquid, and gaseous, combined either with carbon or with both carbon and oxygen in various proportions.

Oxygen is an invisible gas, 16 times as heavy as hydrogen. It is found in the gaseous state, mixed with nitrogen, in air. Combined with $\frac{1}{8}$ of its weight of hydrogen it forms water. It is the universal supporter of combustion, and is the active agent of corrosion or rusting, forming oxides of the metals. It is found combined with hydrogen and carbon in wood and other vegetable products, forming about 40 per cent of the weight of dry wood; and it is found in coal in proportions varying from 2 per cent or less in anthracite to over 25 per cent in some lignites.

Nitrogen is also an invisible gas, 14 times as heavy as hydrogen. It has so little chemical affinity for other substances that it cannot easily be combined with them by ordinary chemical methods. The fixation of the nitrogen of the air, or causing it to combine with alkalies to form fertilizers, is one of the most important problems of the chemist. It is the diluent of oxygen in air, restraining its activity, and causing combustion and corrosion to be less rapid than if they were effected in pure oxygen. It is one of the chief causes of loss of heat in the operation of steam-boilers, since it enters the furnace at the temperature of the atmosphere and escapes in the chimney-gases at a high temperature. It is found in all coals, usually to the extent of from 0.5 to 2 per cent of their weight. When coal is distilled this nitrogen appears in the vapors, combined with hydrogen, as ammonia, NH_3, and when the coal is burned the NH_3 is decomposed and part of the N is oxidized to nitric acid, HNO_3.

Sulphur is found in most coals, in amounts ranging from 0.5 per cent to ocasionally 5 per cent or more in some poor coals. It is contained in them usually as iron pyrites (sulphide of iron), but sometimes as sulphate of lime. It is always an objectionable constituent of coal, since it causes the formation of clinker by the fusion of the ash. It has a slight value as fuel when in the form of sulphide of iron, 1 lb. of sulphur in that form having a heating value about equal to that of ¼ lb. of carbon. In the form of sulphate of lime it has no heating value.

Properties of Air.—Pure dry air is composed of a mixture of

20.91 parts O and 79.09 parts N by volume,

or 23.15 parts O and 76.85 parts N by weight.

The figure 20.91 is the average result of several determinations of oxygen in air, given in Hempel's Gas Analysis. The parts by weight are calculated from this figure, using 15.963 and 14.012 as the relative density, respectively, of oxygen and nitrogen, referred to hydrogen as 1. (Air also contains about 1 per cent, by volume, of argon, but it is not taken account of in ordinary gas analysis, being included with the nitrogen.)

The proportions usually given in text-books are: by volume, 21 O, 79 N; and by weight, 23 O, 77 N.

The proportion of nitrogen to oxygen by weight is $76.85 \div 23.15 = 3.320$; by volume, $79.09 \div 20.91 = 3.782$.

The proportion of air to oxygen by weight is $100 \div 23.15 = 4.320$; by volume, $100 \div 20.91 = 4.782$.

Ordinary atmospheric air, outdoors, contains about 4 parts in 10,000 of carbon dioxide, and a quantity of vapor of water depending upon the temperature and the relative humidity of the atmosphere. The relative humidity is the percentage of moisture contained in the air as compared with the amount it is capable of holding at the same temperature; it is determined by the use of the dry- and wet-bulb thermometer. The degree of saturation for different readings of the thermometer is given in the following tables, condensed from the Hygrometric Tables of the U. S. Weather Bureau.

RELATIVE HUMIDITY, PER CENT.

Dry Thermometer, Deg. F.	Difference between the Dry and Wet Thermometers, Deg. F.																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	26	28	30
	Relative Humidity, Saturation being 100.																										
32	89	79	69	59	49	39	30	20	11	2																	
40	92	83	75	68	60	52	45	37	29	23	15	7	0														
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	11	5	0										
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1						
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6			
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	12	7	
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	22	17	13
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	28	24	21
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	34	30	26
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	38	34	31
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	44	41	38

WEIGHTS IN POUNDS, OF PURE DRY AIR, WATER VAPOR, AND SATURATED MIXTURES OF AIR AND WATER VAPOR AT VARIOUS TEMPERATURES, AT ATMOSPHERIC PRESSURE, 29.921 INCHES OF MERCURY OR 14.6963 POUNDS PER SQUARE INCH. ALSO THE ELASTIC FORCE OR PRESSURE OF THE AIR AND VAPOR PRESENT IN SATURATED MIXTURES.

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Temperatures in Fahrenheit Degrees.	Weight of 1 Cu. Ft. of Pure Dry Air, lb.	Saturated Mixtures of Air and Water Vapor.					
		Elastic Force of the Vapor, In. of Mercury.	Elastic Force of the Air alone, when Saturated Ins. of Mercury.	Weight of the Vapor in 1 Cu. Ft. of the Mixture, or Wt. of 1 Cu. Ft. of Saturated Steam.	Weight of the Air in 1 Cu. Ft. of the Mixture.	Total Weight of 1 Cu. Ft. of the Mixture.	Weight of Water Vapor Mixed with 1 lb. of Air.
0°	0.086354	0.0439	29.877	0.000077	0.086226	0.086303	0.000898
12	0.084154	0.0754	29.846	0.000130	0.083943	0.084073	0.001548
22	0.082405	0.1172	29.804	0.000198	0.082083	0.082281	0.002413
32	0.080728	0.1811	29.740	0.000300	0.080239	0.080539	0.003744
42	0.079117	0.2673	29.654	0.000435	0.078411	0.078846	0.005554
52	0.077569	0.3883	29.533	0.000621	0.076563	0.077184	0.008116
62	0.076081	0.5559	29.365	0.000874	0.074667	0.075541	0.011709
72	0.074649	0.7846	29.136	0.001213	0.072690	0.073903	0.016691
82	0.073270	1.092	28.829	0.001661	0.070595	0.072256	0 023526
92	0.071940	1.501	28.420	0.002247	0.068331	0.070578	0.032877
102	0.070658	2.036	27.885	0.002999	0.065850	0.068849	0.045546
112	0.069421	2.731	27.190	0.003962	0.063085	0.067047	0.062806
122	0.068227	3.621	26.300	0.005175	0.059970	0.065145	0.086285
132	0.067073	4.750	25.171	0.006689	0.056425	0.063114	0.118548
142	0.065957	6.167	23.754	0.008562	0.052363	0.060925	0.163508
152	0.064878	7.929	21.992	0.010854	0.047686	0.058540	0.227609
162	0.063834	10.097	19.824	0.013636	0.042293	0.055929	0.322407
172	0.062822	12.749	17.172	0.016987	0.036055	0.053042	0.471146
182	0.061843	15.965	13.956	0.021000	0.028845	0.049845	0.728012
192	0.060893	19.826	10.095	0.025746	0.020545	0.046291	1.25319
202	0.059972	24.442	5.479	0.031354	0.010982	0.042336	2.85507
212	0.059079	29.921	0.000	0.037922	0.000000	0.037922	Infinite

OXYGEN AND AIR REQUIRED FOR THE COMBUSTION OF CARBON, HYDROGEN, ETC.

	Chemical Reaction.	Lbs. O. per lb. fuel.	Lbs. N = 3.22 ×O.	Air per lb. = 4,32 ×O.	Gaseous product per lb.
Carbon to CO_2........	$C+2O=CO_2$	2⅔	8.85	11.52	12.52
Carbon to CO.........	$C+O=CO$	1⅓	4.43	5.76	6.76
Carbon monoxide to CO_2...............	$CO+O=CO_2$	4/7	1.90	2.47	3.47
Hydrogen to H_2O......	$2H+O=H_2O$	8	26.56	34.56	35.56
Methane, CH_4 to CO_2 and H_2O...........	$CH_4+4O=CO_2+2H_2O$	4	13.28	17.28	18.28
Sulphur to SO_2........	$S+2O=SO_2$	1	3.32	4.32	5.32

DENSITIES OF GASES.

Name.	Symbol.	Specific Gravity. Air = 1.	Wt. of 1 litre. Grams.	Wt. of 1 cu. ft. Lb.	Relative Density. H = 1	Do., approximate figures
Oxygen.........	O	1.10521	1.43003	0.088843	15.96	=16
Nitrogen........	N	0.9701	1.25523	0.078314	14.01	=14
Hydrogen.......	H	0.069234	0.089582	0.005589	1	= 1
Carbon dioxide...	CO_2	1.51968	1.96633	0.122681	21.95	=22
Carbon monoxide.	CO	0.96709	1.25133	0.078071	13.97	=14
Methane........	CH_4	0.55297	0.71549	0.044640	7.99	= 8
Ethylene........	C_2H_4	0.96744	1.25178	0.078100	13.97	=14
Acetylene.......	C_2H_2	0.89820	1.16219	0.73010	12.97	=13
Sulphur dioxide..	SO_2	2.21295	2.86336	0.178646	31.96	=32
Air............	......	1	1.2939	0.080728	14.41	

The first two columns of figures are from Hempel's Gas Analysis, credited therein to Landolt and Börnstein's *Physickalisch-chemische Tabellen.* The litre weights are referred to Berlin. The weights per cubic foot are based on the weight of air given by Rankine, 0.080728 lb. per cu. ft. at 32° F. and atmospheric pressure, and the figures in the column of specific gravities.

Heating Values of Various Substances.—The following table gives the heating values of different pure fuels, as determined by burning them in oxygen in a calorimeter:

HEAT OF COMBUSTION OF VARIOUS SUBSTANCES IN OXYGEN.

	Heat-units.		Authority.
	Cent.	Fahr.	
Hydrogen to liquid water.........	34,462	62,032	Favre and Silbermann.
	34,342	61,816	Thomsen.
Carbon (wood charcoal) to carbon dioxide, CO_2..................	8,080	14,544	Favre and Silbermann.
	8,137	14,647	Berthelot.
Carbon, diamond to CO_2.........	7,859	14,146	"
" black diamond to CO_2....	7,861	14,150	"
" graphite to CO_2..........	7,901	14,222	"
Carbon to carbon monoxide, CO ..	2,473	4,451	Favre and Silbermann.
CO to CO_2, per unit of CO.......	2,403	4,325	" "
	2,385	4,293	Thomsen.
CO to CO_2 per unit of $C = 2\frac{1}{3} \times 2403$	5,607	10,093	Favre and Silbermann.
Methane (marsh-gas), CH_4 to CO_2 and H_2O..................	13,120	23,616	Thomsen.
	13,063	23,513	Favre and Silbermann.
Ethylene (olefiant gas), C_2H_4 to CO_2 and H_2O...............	11,858	21,344	" "
	11,957	21,523	Thomsen.
Benzole gas, C_6H_6 to CO_2 and H_2O.	10,102	18,184	"
	9,915	17,847	Favre and Silbermann.
Acetylene, C_2H_2 to CO_2 and H_2O..	10,109	18,196	Calculated.
Sulphur to SO_2.................	2,250	4,050	N. W. Lord.*

* See Appendix to this chapter, Heating Value of Sulphur in Coal, p. 39.

The heating value of methane, CH_4, if calculated according to its composition by the formula $8080C + 34{,}462H$, using Favre and Silbermann's figures, is

14,675 Centigrade heat-units, instead of 13,063, the value determined by a calorimeter, a difference of 1612 heat-units. The calculated heating value of ethylene, C_2H_4, is 11,849, and that of benzole gas, C_4H_4, is 10,109 heat-units, differing respectively from the calorimetric values only 9 and 7 heat-units.

In calculations of the heating value of mixed fuels the value for carbon is commonly taken at 14,600 British thermal units, which is approximately the average of the figures given by Favre and Silbermann and by Berthelot, and that of hydrogen at 62,000, which is nearly the average of the figures of Favre and Silbermann and of Thomsen.

Taking the heating value of C burned to CO_2 at 14,600 B.T.U., and that of C to CO at 4450, the difference, 10,150 B.T.U., is the heat lost by the imperfect combustion of each pound of carbon burned to CO instead of CO_2. If the CO formed by this imperfect combustion is afterwards burned to CO_2, the lost heat is regained.

Imperfect combustion, burning C to CO, is caused by a deficient air-supply, which is usually due to a great thickness of fire-bed relatively to the force of the draft. With a thick bed of hot coal upon a grate, the carbon in the lower layer, where the air supply is ample, is burned to CO_2, and this gas passing through the upper layers, where the air is lacking, is, if the temperature is sufficiently high, converted more or less into CO, as in the operation of a gas-producer. Complete conversion requires a thick bed of fuel at a high temperature, above 1500° F.

Heat Absorbed by Decomposition.—By the decomposition of a chemical compound as much heat is absorbed or rendered latent as was evolved when the compound was formed. If 1 lb. C. is burned to CO_2, generating 14,600 B.T.U., and the CO_2 thus formed is immediately reduced to CO by passing it through a body of glowing carbon, by the reaction $CO_2 + C = 2CO$, the result is the same as if the 2 lbs. C. had been originally burned to 2CO, generating $2 \times 4450 = 8900$ B.T.U. The 2 lbs. C. burned to CO_2 would generate $2 \times 14,600 = 29,200$ B.T.U., the difference, $29,200 - 8900 = 20,300$ B.T.U. being absorbed or rendered latent in the 2CO, or 10,150 B.T.U. for each pound of carbon.

In like manner if 9 lbs. of water (which might be formed by burning 1 lb. H with the generation of 62,000 B.T.U. and cooling the resulting H_2O to the atmospheric temperature) be injected into a large bed of glowing coal, it will be decomposed into 1 lb. H and 8 lbs. O. The decomposition will absorb 62,000 B.T.U., cooling the

bed of coal this amount, and the same quantity of heat will again be evolved if the H is subsequently burned with a fresh supply of O. The 8 lbs. O will enter into combination with 6 lbs. C, forming 14 lbs. CO (since CO is composed of 12 parts C to 16 parts O), generating $6 \times 4450 = 26{,}700$ B.T.U., and $6 \times 10{,}150 = 60{,}900$ B.T.U. will be latent in this 14 lbs. CO, to be evolved later if it is burned to CO_2 with an additional supply of 8 lbs. O.

Heating Value of Compound or Mixed Fuels.—It is customary to consider the heating value of a compouna or mixed fuel as being equal to the sum of the heating values of its elementary constituents, and to calculate it by means of Dulong's formula, which is, using approximate figures, in British thermal units,

$$\text{Heating value} = \frac{1}{100}\left[14{,}600C + 62{,}000\left(H - \frac{O}{8}\right) + 4050S\right];$$

$$\text{or,}\quad \text{Heating value} = \frac{1}{100}\left[8140C + 34{,}400\left(H - \frac{O}{8}\right) + 2250S\right],$$

in Centigrade units, in which C, H, O, and S are respectively the percentages of carbon, hydrogen, oxygen, and sulphur contained in the fuel. The term $H - \frac{1}{8}O$ is called the "available" or "disposable" hydrogen, or that which is not combined with oxygen in the fuel.

This formula does not apply in the case of a mixed gaseous fuel containing carbon monoxide, since, as shown in the table given above, 1 lb. C in the form of CO generates when burning to CO_2 only 10,093 B.T.U. instead of 14,544 B.T.U. (Favre and Silbermann's values), the difference, 4451 B.T.U., having already been generated when the CO was formed. The formula also does not appear to hold true in the case of some hydrocarbon gaseous fuels, as in the case of methane, mentioned in the note under the table, while on the other hand it does appear to hold in the case of ethylene and benzole.

For all the common varieties of coal, cannel-coal and some lignites being excepted, it is accurate within the limits of error of chemical analyses and calorimetric determinations, as is shown by the recent experiments of Mahler and of Lord and Haas, which are discussed elsewhere in this volume.

"Available Heating Value" of Hydrogen.—Some writers in giving the heating value of hydrogen subtract from its total calorimetric value, 62,000 B.T.U. (found by burning the gas in a calorimeter in which the steam generated by the combustion is condensed and cooled to the temperature of the water in the calorimeter), a quantity rep-

resenting the latent heat of the steam generated, viz., 970.4 B.T.U. per lb. steam, or $9 \times 970.4 = 8733.6$ B.T.U. per lb. hydrogen, making the net heating value of hydrogen "burned to steam at 212°" $62,000 - 8734 = 53,266$ B.T.U. per lb. Others subtract also an additional quantity representing the difference between the heat in the 9 lbs. of water condensed from the steam at 212° and that in the same water when cooled down to a given standard temperature, such as 62°. This difference is 149.9 B.T.U. per lb. water, or $9 \times 149.9 = 1349.1$ B.T.U. per lb. hydrogen, which subtracted from 53,266 gives 51,917 B.T.U. as the available heating value of 1 lb. hydrogen burned with 8 lbs. oxygen, both gases being supplied at 62°, and the product, 9 lbs. H_2O, escaping as steam at 212°.

This use of heating values of hydrogen "burned to steam," in computations relating to combustion of fuel, is inconvenient, since it necessitates a statement of the conditions upon which the figures are based; and it is, moreover, misleading, if not inaccurate, since hydrogen in fuel is not often burned in pure oxygen, but in air, the temperature of the gases before burning is not often the assumed standard temperature, and the products of combustion are rarely discharged at 212°. In steam-boiler practice the chimney-gases are usually discharged at a temperature above 300°; but if economizers are used, and the water supplied to them is cold, the gases may be cooled to below 212°, in which case the steam in the gases is condensed and its latent heat of evaporation is utilized.

If there is any need at all of using figures of the "available" heating value of hydrogen, or of its heating value when "burned to steam," the fact that the gas is burned in air and not in pure oxygen should be taken into consideration. The resulting figures will then be much lower than those above given, and they will vary with different conditions, as shown below.

(1) Suppose 1 lb. H to be burned in just enough air to supply 8 lbs. O, that the H and the air are supplied at 62°, and the products of combustion escape at 212°. We have:

Total heating value of 1 lb. H............		62 000 B.T.U.
Heat lost, latent heat of 9 lbs. H_2O at 212°..	=8734	
9 lbs. H_2O heated from 62° to 212°.......	=1349	
Nitrogen with 8 lbs. O heated from 62° to 212° $=8 \times 3.32 \times 150 \times 0.2438$ (specific heat)............................	= 971	11,054 "
Net available heating value.............		50,946 "

(2) Suppose that the air-supply is double that required to effect the combustion of the H, other conditions being the same as in (1). The additional heat lost will be:

Excess air $8 \times 4.32 = 34.56$ lbs. $\times 150 \times 0.2375$ . . . . =	1,231 B.T.U.
Which will reduce the net heating value to.	49,715 "

(3) Suppose that with the double air-supply the products of combustion escape at 562°. The heat lost will then be as below:

9 lbs. water heated from 62° to 212°.	1,349 B.T.U.
Latent heat of 9 lbs. H_2O at 212°.	8,734 "
Superheated steam, 9 lbs. $\times (562-212) \times 0.48$(sp.ht.)*	1,512 "
Nitrogen, $26.56 \times (562-62) \times 0.2438$	3,238 "
Excess air, $34.56 \times (562-62) \times 0.2375$	4,104 "
Total losses.	18,936 "

Which subtracted from 62,000 gives 41,064 B.T.U. as the net available heating value.

It is better in all calculations of the heating value of fuel and of the results of combustion in steam-boiler practice, to avoid the use of this so-called "available heating value," and to take the heating value of hydrogen (or that part of the hydrogen which is not already combined with oxygen in the fuel) at 62,000 B.T.U. The various heat losses, calculated as above, which vary with the conditions, are then not subtracted from the heating value of the fuel, but are taken as losses of heat in the chimney-gases.

In calculations of the relative commercial value of different fuels containing hydrogen or water, however, account must be taken of the loss of heat due to superheated steam escaping in the chimney-gases.

Available Heating Value of a Fuel containing Hydrogen.—The total heating value of a hydrogenous fuel being

$$14{,}600\mathrm{C} + 62{,}000\left(\mathrm{H} - \frac{\mathrm{O}}{8}\right),$$

to find the available heating value for any assumed temperature of the air-supply and of the chimney-gases, we subtract the heat lost in the superheated steam which escapes into the chimney, or

$$9\mathrm{H} \times [(212° - t) + 970.4 + 0.48(T_c - 212°)],$$

* The specific heat of superheated steam at atmospheric pressure is commonly taken at 0.48. Knobloch and Jakobs' experiments (see Peabody's Steam Tables) give it at 0.463 at 212° F., 0.462 at 302° and 390° F., rising to 0.473 at 752° F.

in which t is the temperature of the air supply and T_c that of the chimney-gases. This calculation takes no account of the nitrogen which is in the air required to burn the hydrogen, nor of the excess air-supply, the loss of heat due to these being considered as part of the loss in the dry chimney-gases, consisting of CO_2, CO, O, and N.

EXAMPLE.—What is the total heating value and the available heating value of 1 lb. of combustible consisting of 0.91C+.05H+.04O, the air for combustion being supplied at 62° and the chimney-gases escaping at 562°?

Total heating value, $0.91\times14{,}600+.045\times62{,}000$ .... =16,076 B.T.U.
Heat lost in steam, $9\times.05[150+970+(0.48\times350)]$ .... = 580 "

Difference, or available heating value .... 15,496 "

The heat lost in the steam is about 3.5% of the total heating value.

Available Heating Value of a Fuel Containing Hydrogen and Water.—In this case the heat lost includes, besides that due to the superheated steam formed by the combustion of the available hydrogen, that is, the hydrogen of the dry fuel less one eighth of the oxygen of the dry fuel, the heat due to the superheated steam formed from the water in the fuel, or

$$(9H + W) \times [212 - t) + 970 + 0.48(T_c - 212)],$$

in which W is the water in 1 lb. of the fuel.

EXAMPLE.—What is the available heating value of 1 lb. of moist wood whose analysis is 38C, 5H, 32O, 1 ash, 24 water, = 100%, the air being supplied at 62° F. and the chimney-gas escaping at 412°?

Total heating value, $38 \times 14{,}600 + (5 - 4) \times 62{,}000$ .... = 6168 B.T.U.
Heat lost in superheated steam $(9 \times .05 + 0.24)$
$\times [150 + 970 + (0.48 \times 200)]$ .... = 839 "
Available heating value .... = 5329 "

The heat loss in the steam in this case is nearly 14% of the total heating value.

Temperature of the Fire.—Assuming that a pure fuel, such as carbon, is thoroughly burned in a furnace, all of the heat generated will be transferred to the gaseous products of combustion, raising their temperature above that at which the fuel and the oxygen or air are supplied to the furnace. Suppose that 1 lb. C is burned with $2\frac{2}{3}$ lbs. O, forming $3\frac{2}{3}$ lbs. CO_2, both the C and the O being supplied at 0° F.

The combustion of the 1 lb. C generates 14,600 B.T.U., which will all be contained in the $3\frac{2}{3}$ lbs. CO_2. The specific heat of CO_2 is 0.217; that is, it requires 0.217 B.T.U. to raise the temperature of 1 lb. of CO_2 one degree Fahrenheit. To raise $3\frac{2}{3}$ lbs. CO_2 one degree will require $3\frac{2}{3} \times 0.217 = 0.7957$ B.T.U., and 14,600 B.T.U. will therefore raise its temperature $14,600 \div 0.7957 = 18,350°$ F. above the temperature at which the C and the O were supplied. The temperatures thus calculated are known as theoretical temperatures, and are based on the assumptions of perfect combustion and no loss by radiation. The temperature of 18,350° is far beyond any temperature known in the arts, and it is probable that long before it could be reached the phenomenon of dissociation would take place; that is, the CO_2 would be split up into C and O, and the elements would lose their affinity for each other.

The theoretical elevation of temperature of the fire may conveniently be calculated by the formula

$$\text{Elevation of temp.} = \frac{\text{B.T.U. generated by the combustion}}{\text{Weight of gaseous products} \times \text{their sp. heat}}.$$

It is evident from this formula that the rapidity of the combustion, or the time required to burn a given weight of fuel, has nothing to do with the temperature that may theoretically be attained. In practice the temperature of a bed of coal in a furnace and that of the burning gases immediately above the coal are reduced to some extent by radiation, and as the quantity of heat radiated from a given mass of fuel is a function of the time during which it takes place, a considerable portion of the heat generated may be lost by radiation when the combustion is very slow. With ordinary rates of combustion, however, say 10 lbs. of coal per sq. ft. of grate surface per hour, and fire-brick furnaces, the percentage of loss of heat by radiation is quite small, 1% or less, and the actual temperature that may be attained will be very nearly as high with that rate of combustion as with a rate of 20 or 40 lbs.

Maximum Theoretical Temperature due to Burning Carbon in Dry Air.—1 lb. C burned to CO_2 generates 14,600 B.T.U. The products of combustion are $3\frac{2}{3}$ lbs. $CO_2 + 2\frac{2}{3} \times 3.32 = 8.853$ lbs. $N = 12.52$ lbs. gas. Taking the specific heat of CO_2 at 0.217, and that of N at 0.2438, we have for the specific heat of the gas

$$(3\tfrac{2}{3} \times 0.217 + 8.853 \times 0.2438) \div 12.52 = 0.2359.$$

The elevation of temperature of the fire above the atmospheric temperature is $14,600 \div (12.52 \times 0.2359) = 4942.5°$.

If the atmospheric temperature is 62° F., then the temperature of the fire is $4942.5 + 62 = 5004.5°$.

The temperatures found by the above calculations can never be reached in practice, since it is not possible to effect complete combustion without a considerable excess of air above the theoretical requirement. The fact that the specific heat of the gases of combustion, at high temperatures, is higher than the figures given, would also have the effect of reducing the temperature.

Taking the specific heat of the gases at 0.237, the figure commonly taken in temperature calculations, the calculated elevation of temperature is $14,000 \div (12.52 \times 0.237) = 4920°$ F.

TEMPERATURE OF THE FIRE, CARBON BEING BURNED PART TO CO AND PART TO CO_2.

Heating value of 1 lb. C burned to CO_2...... 14,600 B.T.U.
" " " " " " " CO....... 4,450 "

Air supply below 11.52 lbs., per cent	0	10	20	30	40	50
Air per lb. C, lbs.	11.52	10.37	9.22	8.06	6.91	5.76
Air + C = gas, lbs.	12.52	11.37	10.22	9.06	7.91	6.76
C burned to CO_2, per cent	100	80	60	40	20	0
C " " CO, " "	0	20	40	60	80	100
B.T.U. generated in making CO_2	14,600	11,680	8,760	5,840	2,920	0
B.T.U. generated in making CO	0	890	1,780	2,670	3,560	4,450
Total heat generated	14,600	12,570	10,540	8,510	6,480	4,450
Loss due to CO, B.T.U.	0	2,030	4,060	6,090	8,120	10,150
Elevation of temperature of fire (taking specific heat of gases at 0.24)	4860°	4606°	4298°	3914°	3418°	2743°
Gas analysis by volume: CO_2	20.86	18.12	14.87	10.94	6.10	0
Gas analysis by volume: CO	0	4.53	9.91	16.41	24.42	34.51
Gas analysis by volume: N	79.14	77.35	75.22	72.65	69.48	65.49

TEMPERATURE OF THE FIRE, CARBON BURNED TO CO_2 WITH EXCESS OF AIR.

Air-supply above 11.52 lbs. per cent	25	50	75	100	150	200
Air per lb. C, lbs.	14.40	17.28	20.16	23.04	28.80	34.56
Air + C = gas, lbs.	15.40	18.28	21.16	24.04	29.80	35.56
Elevation of temperature of fire	3950°	3328°	2875°	2530°	2041°	1711°
Gas analysis by volume: CO_2	16.69	13.91	11.92	10.43	8.34	6.95
Gas analysis by volume: O	4.17	6.95	8.94	10.43	12.52	13.91
Gas analysis by volume: N	79.14	79.14	79.14	79.14	79.14	79.14

Maximum Theoretical Temperature due to Burning Hydrogen in Dry Air.—1 lb. H burned to H_2O generates 62,000 B.T.U. The products of combustion are 9 lbs. H_2O (superheated steam) and

$8 \times 3.32 = 26.56$ lbs. N. Let t = temperature of the atmosphere and $T + t$ = temperature of the products of combustion, 0.48 = specific heat of superheated steam, and 0.2438 = specific heat of nitrogen. Then

$$62{,}000 = 9[(212 - t) + 970.4 + 0.48(T + t - 212)] + 26.56 \times 0.2438\,T.$$

$212 - t$ is the B.T.U. required to heat 1 lb. of water from t to 212°. 970.4 is the latent heat of evaporation at 212°, and $0.48(T+t-212)$ is the heat required to heat 1 lb. of steam from 212° to $T + t$.

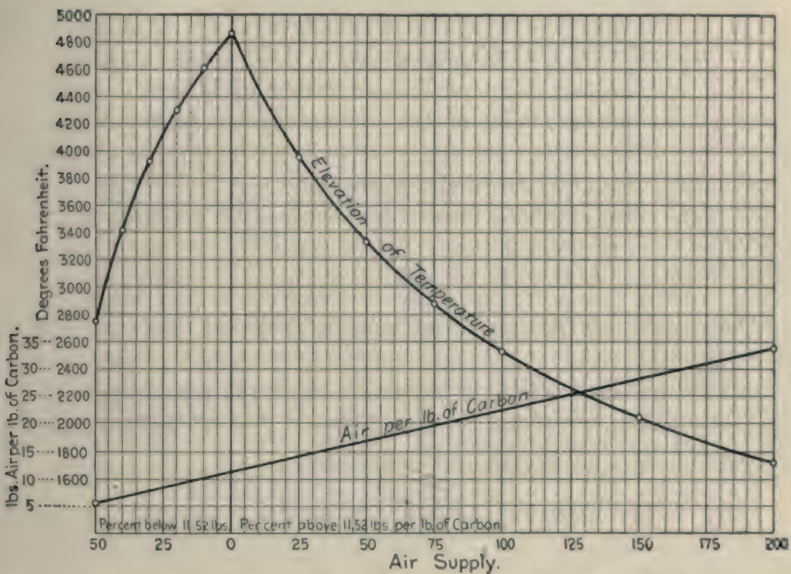

FIG. 1.—MAXIMUM THEORETICAL TEMPERATURE OF THE FIRE DUE TO BURNING CARBON WITH DIFFERENT QUANTITIES OF AIR.

Taking t at 62°, we have

$$62{,}000 = 9[1044.6 + 0.48T] + 6.475T$$
$$= 90401.4 + 10.795T.$$

Whence $T = 4872.5$, and $T + t = 4934.5°$ F.

The maximum theoretical temperature due to burning hydrogen in air and that due to burning carbon in air are very nearly the same.

Temperature of the Fire, the Fuel containing Hydrogen and Water.—The gaseous products of combustion in this case will contain

superheated steam, formed from the combustion of the hydrogen in the coal and the evaporation of the moisture. The calculation of the temperature of the fire, assuming perfect combustion and no loss by radiation, may be made in the following manner. Reduce the analysis of the fuel in percentages of C, H, O, and moisture to decimal parts of 1 lb.

Let $H_1 = H - \frac{1}{8}O$ = available hydrogen;
W = moisture in the fuel,
T = elevation of the temperature of the fire above the atmospheric temperature;
t = temperature of the atmosphere, say 60° F.;
L = latent heat of evaporation at 212° = 970.4;
a = heating value of 1 lb. of carbon = 14,600;
b = heating value of 1 lb. of hydrogen = 62,000;
f = lbs. of dry gas per lb. of fuel = CO_2 + N + excess air;
c = specific heat of the gas = 0.237;
$9H$ = lbs. of steam formed by burning the available H;
$W + 9H$ = superheated steam in the gases;
0.48 = specific heat of superheated steam.

The total heat developed by burning 1 lb. of the fuel will be $aC+bH_1$ heat units.

All of this heat will be utilized in raising the temperature of the gas and steam to $T°$ above the atmosphere. The dry gas will contain cfT heat-units, and the superheated steam

$$(W+9H)[212-t+L+0.48(T+t-212)].$$

We have then

$$aC+bH_1 = 0.237fT + (W+9H)[212-t+L+0.48(T+t-212)]$$
$$= [0.237f + 0.48(W+9H)]T + (W+9H)(1080.6-0.52t).$$

Transposing,

$$T = \frac{aC + bH_1 - (W+9H)(1080.6-0.52t)}{0.237f + 0.48(W+9H)}. \quad . \quad . \quad . \quad (1)$$

Substituting for a, b, and H_1 their values, and taking $t = 62°$,

$$T = \frac{14{,}600C + 62{,}000(H - \frac{1}{8}O) - 1048.4(W+9H)}{0.237f + 0.48(W+9H)}. \quad . \quad . \quad (2)$$

Taking C, H, O, and W in percentages, instead of in decimal parts, the formula reduces to (a very close approximation)

$$T = \frac{616C + 2220H - 327O - 44W}{f + 0.02W + 0.18H}. \quad . \quad . \quad . \quad . \quad (3)$$

EXAMPLES.—1. Given a coal whose analysis, excluding ash and sulphur, is 75C, 5H, 10O, and 10 moisture, with dry gas=20 lbs. per lb. of this combustible, including moisture:

$$T = \frac{616 \times 75 + 2220 \times 5 - 327 \times 10 - 44 \times 10}{20 + 0.02 \times 10 + .18 \times 5} = 2540°;$$

$$T + t = 2602° \text{ F.}$$

The first of the two formulæ gives 2600° F.

The sulphur in coal may be neglected in calculations of temperature, since 3 per cent of sulphur would not increase the temperature one per cent, taking 4000 B.T.U. as the heating value of sulphur. The error due to neglecting it is less than the probable error of the figure, 0.237, for the specific heat of furnace-gases at high temperatures.

2. Required the maximum temperature attainable by burning moist wood of the composition C, 38; H, 5; O, 32; ash, 1; moisture, 24; the dry gas being 15 lbs. per lb. of wood, and temperature of the atmosphere 62°.

$$T = \frac{616 \times 38 + 2220 \times 5 - 327 \times 32 - 44 \times 24}{15 + 0.02 \times 24 + 0.18 \times 5} = 1403°;$$

$$T + t = 1465°.$$

3. Since the carbon and the available hydrogen make only 39% of the weight of the wood, a much smaller air-supply than that required to make 15 lbs. of dry gas per lb. of wood may be sufficient to effect complete combustion. If we take the dry gas at 10 lbs. instead of 15, the temperature T will be

$$T = \frac{22988}{10 + 1.38} = 2020°.$$

4. Required the theoretical temperature of a fire of Pocahontas coal of the following anaylsis: C, 84.22; H, 4.26; O, 3.48; N, 0.84; S, 0.59; ash, 5.85; water, 0.76; the dry gas being 20 lbs. per lb. of combustible, the heating value of the S being neglected.

The combustible, C, H, O, and N, is 92.80% of the coal;

$$f = 20 \times .928 = 18.56.$$

$$T = \frac{616 \times 84.22 + 2220 \times 4.26 - 327 \times 3.48 - 44 \times 0.76}{18.56 + 0.02 \times 0.76 + .18 \times 4.26} = 3110°;$$

$$T + t = 3110 + 62° = 3172°.$$

Pure carbon burned with 19 lbs. air per lb., making 20 lbs. of gas, by the same formula gives $T = 3080$, $T + t = 3142$. The semi-bituminous coal therefore gives a trifle higher temperature than pure carbon.

Actual Temperature of the Fire usually Less than the Theoretical. —In order to realize in practice the temperatures given by the above theoretical calculations, it is necessary that the air be delivered to the incandescent fuel at a perfectly uniform rate; that the combustion of the hydrogen be complete; that the combustion of the carbon be complete, forming CO_2 when the air supply equals or exceeds 11.52 lbs. per lb. of carbon burned, or, when the air-supply is less than this, that all of its oxygen be used to form either CO or CO_2; and that there be no loss by radiation from the incandescent fuel into the surrounding furnace or boiler walls. These conditions can be nearly obtained under some circumstances, such, for instance, as with gaseous fuel with an intimate and regular admixture of air, the combustion taking place in a chamber with thick fire-brick walls; with dust fuel burned under similar conditions; and with a thick fire of anthracite, egg size, burned in a fire-brick chamber with a steady draft, after the freshly fired uper layer of coal has reached the temperature of the furnace. With insufficient air-supply the actual temperature is always less than the theoretical, for the reason that some of the oxygen passes through the fire without entering into combination with carbon. Generally the air-supply is not regular, even with a steady draft pressure, for the reason that the freshly fired coal chokes to some degree the air-passages through the bed, causing the formation of some CO and chilling the furnace. When the fire-bed is directly underneath the comparatively cool surface of the boiler, radiation from the bed reduces the furnace temperature.

The author has obtained temperatures exceeding 3000° F., as measured by a Uehling & Steinbart recording pneumatic pyrometer, with Pittsburg coal containing less than 2% of moisture, and having a heating value of 15,000 B.T.U. per lb. of dry combustible. The conditions were a fire-brick combustion-chamber and frequent firing of small

quantities of coal at a time. This corresponds nearly to the theoretical temperature due to an air-supply of 18 lbs. per lb. of combustible, which is about the figure found in practice to give the highest efficiency of steam-boiler performance.

Excessive Carbon Monoxide produced by Heavy Firing.—A series of experiments by J. C. Hoadley (Trans. A. S. M. E., vol. vi. p. 794), in which for three hours anthracite egg coal was fired on the grates at the rate of 200 lbs. in each half-hour, when the rate at which the coal was burned was only about 140 lbs., thus steadily increasing the thickness of the bed of coal, showed the following results, the gases being analyzed every half-hour:

Half-hour periods	1	2	3	4	5	6*	7*	8
CO in gases, per cent	2.54	2.99	3.99	4.61	4.70	4.81	0.25	0.21
CO_2 " " " "	5.12	5.55	7.79	7.70	7.82	8.01	15.21	14.11
Lbs. air per lb. coal	33.2	29.5	21.4	20.1	19.8	19 3	19.3	20.8

* Intervals of one hour.

The firing was at the rate of 200 lbs. of coal every half-hour until 11.15 A.M., or fifteen minutes before the sixth sample of gas was taken. The next lot of 200 lbs. coal was not fired until 12.45 P M., and no more was fired until after the eighth sample of gas was taken. The seventh sample was taken at 12.30, and the eighth at 1.30, each forty-five minutes after firing 200 lbs. of coal. The results show a steady increase in CO up to 11.30 A.M., as the bed of coal became thicker, and a reduction to a low figure when the bed became thin.

These tests show that it is sometimes possible for a high percentage of CO and a great excess of air-supply to exist at the same time. This may be explained by supposing that the excess of CO was generated at one portion of the grate surface, and that the excess of air entered at another—or else leaked into the boiler-setting beyond the bridge-wall—and that the two currents, one of CO and the other of air, were never brought into contact until their temperature was reduced below the point of ignition.

Calculation of the Weight of Air supplied, and the Weight of the Gases, from the Analysis of the Gases by Volume.*—Given a coal con-

* To convert analysis by volume into analysis by weight, multiply the percentage of each constituent gas by its relative density, viz., CO_2 by 11, O by 8, CO and N each by 7, and divide each product by the sum of the products. *Per contra*, to convert analysis by weight into analysis by volume, divide the percentage by weight of each gas by its relative density, and divide each quotient by the sum of the quotients.

taining 66C, 5H, 8O, 1N, 8 water, and 12 ash, = 100%, it is required to compute the analysis, by weight and by volume, of the gaseous products of combustion, on the assumptions (1) that 60C is burnt to CO_2 and 6 to CO; (2) that the supply of dry air is 20% in excess of that required to effect this combustion of the C and to burn the available H ($= H - \frac{1}{8}O$) to H_2O; and (3) that the dry air is accompanied by 1% of its weight of moisture. It is also required to determine the weight of dry air and of dry gas per lb. of carbon and per lb. of fuel, and furthermore to find formulas by means of which these weights may be computed directly from the analysis of the gases by volume.

We first construct a table in which are shown the elements of the coal and of the air which combine to form the gaseous products, as follows:

Per cent or Parts in 100 Lbs. Fuel.	O from the Air.	N from the Air = O × 3.32	Total Air.	CO_2.	CO.	H_2O.
60C to CO_2 × $2\frac{2}{3}$ =	160	531.20	691.20	220	....	
6C to CO × $1\frac{1}{3}$ =	8	26.56	34.56	.....	14	
4H to H_2O × 8 =	32	106.24	138.24	.....	....	36
	200	664.00	864.00			
1 H, 8O } to H_2O......	....	....	....	......	......	9
1 N.............	....	1.00				
8 water..........	....	....	....	......	......	8
12 ash						
100						
Excess air, 20%.....	40	132.80	172.80			
Total dry air........	....	....	1036.80			
Moisture in the air...	....	....	....	......	......	10.4
Total gases, 1135.2 =	40	797.8	....	220	14	63.4

Total dry gases 1071.80 or 3.732 74.436 .... 20.526 1.306% by wt.
Total dry gases % by vol. 3.547 80.847 .... 14.187 1.419
Total gas 1135.2 + 12 ash = 100 coal + 1036.80 air + 10.4 moisture in air.
Dry gas per lb. coal 10.718 lbs.; per lb. C = 1071.8 ÷ 66 = 16.239 lbs.
Dry air per lb. coal 10.368 lbs.; per lb. C = 1036.8 ÷ 66 = 15.709 lbs.

The air and gas per lb. coal and per lb. C may be calculated from the analysis of the gases by weight or by volume, as follows:

Let $CO_2 + O + CO + N$ = total gas, in percentages, by weight. The carbon in the $CO_2 = \frac{3}{11}CO_2$, and that in the $CO = \frac{3}{7}CO$. This carbon was supplied by the fuel. We then have

$$\text{Dry gas per lb. C} = \frac{CO_2 + O + CO + N}{\frac{3}{11}CO_2 + \frac{3}{7}CO} = \frac{100}{\frac{3}{11}CO_2 + \frac{3}{7}CO}.$$

Multiplying the result by the C in 1 lb. coal gives the dry gas per lb. of coal.

Multiplying each term in this formula by the respective figures for relative density of the several gases, viz., CO_2, 11; O, 8; CO and N, 7, we obtain

$$\text{Dry gas per lb. C} = \frac{11CO_2 + 8O + 7(CO + N)}{3(CO_2 + CO)},$$

in which CO_2, O, CO, and N are percentages by volume. Taking the percentage by volume given in the above table, we have

$$\text{Dry gas per lb. C} = \frac{11 \times 14.187 + 8 \times 3.547 + 7 \times 82.266}{3(14.187 + 1.419)}$$
$$= 16.239 \text{ lbs., as before.}$$

$$\text{Dry gas per lb. coal} = 16.239 \times .66 = 10.718 \text{ lbs.}$$

Th 7N in the last formula represents the N supplied by the air, plus the relatively insignificant amount of about 1 part in 800 furnished by the coal, as shown in the table. As the N supplied by the air is 76.85%, or $3.32 \div 4.32$, of the weight of the air, we have

$$\text{Dry air per lb. C} = \frac{7(N - \frac{1}{800}N)}{3(CO_2 + CO)} \times \frac{432}{332} = \frac{3.032N}{CO_2 + CO},$$

in which CO_2, CO, and N are percentages by volume of the dry gas.

This last formula is a most useful one for computing the air-supply per lb. C from the analysis of the gases by volume. Substituting the percentages found in the example, we have

$$\text{Dry air per lb. C} = \frac{3.032 \times 80.847}{14.187 + 1.419} = 15.707 \text{ lb.,}$$

which is practically the same as the result obtained from the table.

Excess of Air-supply above the Theoretical Minimum Requirement.—Referring to the table of computations in the above example, p. 34, it will be seen that all the nitrogen in the gases, 80.847% by volume, came from the total air-supply, except an insignificant amount furnished by the coal. The oxygen, 3.547%, all came from the excess air-supply. This oxygen was accompanied in the excess air-supply with 3.782 times its volume of nitrogen, or $3.782 \times 3.547 = 13.415N$. The difference between 80.847 and $13.415 = 67.432$ is

the N of the air theoretically required to burn the coal to CO and CO, as in the example, and the quotient, $80.847 \div 67.432 = 1.199$, is the ratio of the total air-supply to that theoretically required. Subtracting 1 from this ratio and multiplying by 100 gives 19.9% as the calculated percentage of excess air-supply, a close approximation to the 20% originally assumed in computing the table. The formula for computing the ratio of air-supply to that theoretically required for the incomplete combustion stated is $\frac{N}{N - 3.782O}$ in which N and O_2 are respectively the percentages of N and O by volume in the dry gas.

If all the C had been burned to CO_2 the air required for complete combustion would have been $864 + 34.56 = 898.56$, and the ratio of the total air used, 1036.80 to 898.56 is 1.153, that is 15.3% excess. The formula for the ratio of the total air supply to that required for complete combustion is

$$\frac{N}{N-3.782(O-\frac{1}{2}CO)}.$$

Applying it to the example,

$$\frac{80.847}{80.847-3.782(3.547-0.710)}=1.153, \text{ as above.}$$

Air Supply Required for Different Grades of Coal.—Taking 50 per cent excess air supply above the theoretical amount required to effect complete combustion, the following formula may be used to obtain the amount of air required for any coal whose ultimate analysis is known:

$$\text{Lbs. air per lb. coal} = 1.5 \times [11.52C + 34.56(H - \tfrac{1}{8}O)],$$

C, *H* and *O* being respectively the carbon, hydrogen and oxygen in 1 pound of coal, or the percentage divided by 100. Dividing the result by combustible or by the carbon in 1 pound of coal gives the pounds of air required per pound combustible or per pound carbon.

Calculations of the air supply for the several varieties of coal whose analyses are given in the following table, give the results shown below.

ULTIMATE ANALYSIS OF COAL DRIED AT 105° C.

Kind of Coal	Anth.	Semi-anth.	Semi-bit.	Bit., Pa.	Bit., Ohio.	Lignite, Texas.	Crude Oil, Texas.
Carbon	76.86	78.32	86.47	77.10	75.82	64.84	84.8
Hydrogen	2.63	3.63	4.54	4.57	5.06	4.47	11.6
Oxygen	2.27	2.25	2.68	6.67	10.47	16.52	1.1
Nitrogen	0.82	1.41	1.08	1.58	1.50	1.30	0.8
Sulphur	0.78	2.03	0.57	0.90	0.82	1.44	1.7
Ash	16.64	12.36	4.66	9.18	6.33	11.43	
POUNDS AIR REQUIRED FOR COMBUSTION							
Per lb. dry coal	14.50	15.27	17.12	15.26	15.04	12.45	
Per lb. combustible	17.39	17.42	17.96	16.81	16.05	14.06	20.60
Per lb. carbon	18.86	19.50	19.40	19.65	19.84	19.21	24.29

Having the proximate analysis only, a close approximation to the number of pounds of air required per pound of combustible, in order to have the air supply 50 per cent in excess, is as follows:

	Lbs.
Anthracite and semi-anthracite	17.4
Semi-bituminous	18.0
Bituminous, Pennsylvania	17.0
Bituminous, Ohio	16.0
Lignite, Texas	14.0
Crude oil, Texas	20.6

Heat Carried Away by the Dry Chimney Gases per Pound of Combustible.*

Per cent CO_2 in Gases.	Pounds Air per Lb. Combustible.	Temperature of Chimney Gases, Deg. Fahr. 300°	350°	400°	450°	500°	550°	600°	650°
		Heat Wasted, Per cent of Total Heat in Coal.							
21.0	12	5.2	6.2	7.3	8.7	9.5	10.5	11.6	12.7
16.8	15	6.0	7.6	9.1	10.3	11.6	13.0	14.3	15.6
14.0	18	7.2	9.1	10.7	12.2	13.9	15.4	17.0	17.9
12.0	21	8.7	10.5	12.3	14.2	16.0	17.8	19.5	21.0
10.0	24	9.9	12.0	14.0	16.1	18.2	20.3	22.4	24.4
9.3	27	11.1	13.5	15.7	18.1	20.4	22.7	25.0	27.4
8.4	30	12.4	14.9	17.4	20.0	22.6	25.0	27.8	30.4
7.6	33	13.5	16.3	19.2	22.0	24.7	27.6	30.5	33.2
7.0	36	14.7	17.8	20.8	23.9	27.0	30.0	33.0	36.6
6.5	39	15.9	19.2	22.5	25.8	29.2	32.4	35.7	39.0
6.0	42	17.1	20.6	24.7	27.7	31.3	34.8	39.4	42.0

* From Bulletin 100 of the Uehling Instrument Co.

Errors in Analysis of Furnace Gas Shown by Computation.*—In connection with an evaporative test of a steam boiler, the following average analysis of the chimney gases was reported by a chemist:

CO_2, 8.2; CO, 0.6; O, 7.5; N, by difference, 83.7.

The ultimate analysis of the coal showed 3.6 per cent H in the coal, dry and free from ash. The air used per pound of carbon, as found by the formula:

$$\text{Lbs. air per lb. C} = \frac{3.032N}{CO_2 + CO},$$

in which N, CO_2 and CO are percentages by volume, was 28.65 lbs. This figure is, however, incorrect, not on account of any error in the formula, but on account of an error in the analysis. It may be shown that 83.7 per cent N in the chimney gas cannot be obtained by any practicable method of burning this coal with air.

The percentages of N in the dry gas, by volume, due to burning C and H in different proportions, without excess of air, are as follows:

	% N.
C burned to CO_2	79.14
C burned to CO	65.48
H burned to H_2O	100.00
CH_4 burned to CO_2 and H_2O	87.19
93C+7H to CO_2 and H_2O	82.0
96C+4H to CO_2 and H_2O	81.0
84C+16CH_4 to CO_2 and H_2O	81.0
84C+16CH_4, the CH_4 escaping unburned	77.8
84C+12C+4H, the 12C escaping as soot	81.3

We thus see that there is no way in which this coal can be burned which will give N higher than 81.3 per cent, and even in the supposed case in which all the CH_4 is unburned and escapes in the gases the sum of N and CH_4 is only 77.8 per cent.

All the above calculations are based on the assumption that there is no excess of air, but the analysis shows 7.5 per cent free O. There must therefore have been a considerable excess, which would cause the percentage of N to be lower, and to approach 79.14.

The only conclusion that can be drawn from these calculations is that the N by difference is largely in error, and that the CO_2, CO, and O reported are either or all of them too small. The analysis being wrong, it is impossible to figure from it the number of pounds of air per pound of fuel, or to compute a heat balance from the results of the boiler test.

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* Stevens Institute Indicator, Oct., 1903.

The CO reported is not likely to be greatly in error, since there was such a large excess of air. The O also was probably nearly correct, since the phosphorus (which was used in the tests) is an excellent absorbent. The greater part of the error is most likely to be in the CO_2, due to its partial absorption by water in the collecting tank. If we take 80 per cent as a probable figure for the N, and add the difference, 3.7, to the CO_2 we obtain

$$\frac{80 \times 3.032}{11.9 + 0.6} = 19.4 \text{ lbs. air per lb. of C,}$$

instead of 28.65 lbs. originally calculated.

Analyses of furnace gases are frequently reported in which the N by difference is given from 81 to 84, leading to wrong conclusions as to the air used for pound of fuel. There is a possibility, however, that high percentages of nitrogen (by difference) may be obtained if samples of gas are withdrawn from the furnace during the period immediately after firing, when hydrocarbons are being distilled rapidly and little or no carbon is being burned. In that case the gases could be high in hydrocarbons, and so would increase the apparent nitrogen as reported in the anaylsis.

The burning of oils and of gases high in hydrogen makes a flue gas high in nitrogen if burned without great excess of air. A petroleum of the composition 85C, 12H, 3O, N and S, burned without excess air makes a gas containing 84.9N; and a gas, CH_4, as shown in the above table, gives 87.19N.

APPENDIX TO CHAPTER II.

I. Heating Value of Sulphur (as Iron Pyrites) in Coal.*

A sample of Pocahontas coal having a calorific value of 8062 (calories) and containing 0.57 per cent of sulphur was mixed with pyrites in two proportions, nine of coal to one of pyrites, and eight of coal to two of pyrites. The coal and pyrites were separately reduced to fine powder and then mixed by rubbing in a mortar. The mixtures were then compressed into cylinders for combustion in the bomb [the Mahler calorimeter]. The pyrites used was a selected crystal of FeS_2.

The results of the two experiments were respectively 6140 and 5150 units for the heat due to a unit of sulphur as pyrites.

These two results do not "check" very well, but it seems safe to conclude that the heat due to the combustion of pyrites in the bomb

* By Prof. N. W. Lord. Trans. Am. Inst. Mining Engineers, vol. xxvii 1897, p. 960.

is somewhere about 5500 units per unit of sulphur. Of course the sulphur is here burned to SO_3, or rather to dilute H_2SO_4, and gives more heat than when it burns in air to SO_2. Pyrites contains 53.3 per cent S. Translating the above result (5500) into heat developed per unit of FeS_2 gives 2931 heat units.

Berthelot gives for the heat of formation of dilute H_2SO_4 what is equivalent to 4388 units per unit of sulphur; and assuming 1582 as the heating value of iron burned to magnetic oxide (Andrews), a calculation for the heating value of pyrites would give:

0.533 S	2339
0.467 Fe	739
Calculated heat	3078

The S being burned to dilute H_2SO_4.

This corresponds to the value found well enough to show that when pyrites burns, the iron and sulphur give nearly the same heat they do when *burned separately in the free state*, which justifies the introduction into Dulong's formula of the sulphur term. As to the number I have adopted in the formula (2250) * for the heat developed when S burns to SO_2, it was taken as an average of several published figures, and is probably a little too high, but not enough out of the way to affect the results noticeably, especially as the heat due to the combustion of the iron was omitted, which it would appear should have been included, though it would have amounted to very little.

II. Hygrometric Properties of Coals.†

Two lines of investigation were undertaken for the purpose of ascertaining the relative qualities of various coals when in the same physical condition with reference to absorbing moisture from the atmosphere.

First, a number of samples of different coals were reduced to a uniform physical condition by grinding or powdering; were then thoroughly dried, and afterward simultaneously exposed to a saturated or nearly saturated atmosphere, for a period of from six to eight days as required, to obtain constant weight. The weight of moisture was checked by thoroughly drying and reweighing.

Second, an investigation was made to determine the effect of the size of particles upon the power to absorb moisture; the investigation being similar in nature to that previously described.

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* The heat-units in this paper are calories per gram. 2250 calories per gram = 4050 B.T.U. per lb.

† From a paper by Prof. R. C. Carpenter in Trans. A. S. M. E., vol. xviii. p. 938.

In drying, the coal was heated to a temperature of from 220 to 240 degrees Fahr., and maintained in that condition for one hour.

Results indicate a great difference in the absorptive power of different coals when in the same physical state, but show, however, a striking similarity in this respect of coals which are known to possess similar qualities from the same geographical districts. With few exceptions, the power of absorbing and retaining moisture is less as the calorific value is greater.

The maximum amounts of moisture absorbed by coals powdered so as to pass No. 80 sieve were as follows:

Anthracite.—10 samples, 4.66 to 6.37%; average, 5.60%.
Eastern Coking Coals.—6 samples, 0.69 to 3.16%; average, 1.92%.
Illinois and Indiana Coals.—6 samples, 4.65 to 14.10%; average, 9.77%.

In the second investigation the pieces of coal were made as nearly equal as possible considering their irregular shape of definite sizes. The results given below show an increase in absorptive power as the size of the particle is diminished.

Size	1 in.	½ in.	¼ in.	Fine.
Illinois	4.55	5.80	5.26	9.30
Cumberland	2.17	3.76	5.61	6.42
Lehigh anthracite egg	1.39	2.03	2.55	5.95
" " pea	.62	.66	1.31	1.59

In connection with the drying of coals at temperatures above the boiling point a number of experiments were made to determine whether there was any sensible loss of volatile matter, but so far as could be determined by repeated trials alternately drying and moistening and by varying time of drying from one to three hours, no loss of volatile matter could be detected, and it seems exceedingly probable that no loss of importance occurs at temperatures below 300° F.

For this reason it would seem entirely safe to use this method of drying coals in testing-boilers, as it is easily applied, and has given very satisfactory and uniform results for the writer whenever used,

CHAPTER III.

COAL.

Production of Coal in the United States.—The extent of the coal industry of the United States, which keeps pace with the growth of manufacturing and with the increase of wealth, is shown by the following figures taken from "Mineral Resources of the United States for the Calendar Year 1910" published by the U. S. Geological Survey.

COAL PRODUCTION OF THE UNITED STATES IN 1910, BY STATES, IN SHORT TONS.*

State or Territory.	Total Quantity.	Total Value.	Average Price per Ton at the Mine.	Average Number of Employees.
Alabama	16,111,462	$20,236,853	$1.26	22,230
Arkansas	1,905,958	2,979,213	1.56	5,568
California and Alaska	12,164	33,336	2.74	19
Colorado	11,973,736	17,026,934	1.42	15,864
Georgia	177,245	259,122	1.46	386
Idaho	4,448	17,426	3.92	14
Illinois	45,900,246	52,405,897	1.14	72,645
Indiana	18,389,815	20,813,659	1.13	21,878
Iowa	7,928,120	13,903,913	1.75	16,666
Kansas	4,921,451	7,914,709	1.61	12,870
Kentucky	14,623,319	14,405,887	.99	20,316
Maryland	5,217,125	5,835,058	1.12	5,809
Michigan	1,534,967	2,930,771	1.91	3,575
Missouri	2,982,433	5,328,285	1.79	9,691
Montana	2,920,970	5,329,322	1.82	3,837
New Mexico	3,508,321	4,877,151	1.39	3,585
North Dakota	399,041	595,139	1.49	534
Ohio	34,209,668	35,932,288	1.05	46,641
Oklahoma	2,646,226	5,867,947	2.22	8,657
Oregon	67,533	235,229	3.48	153
Pennsylvania, bituminous	150,521,526	153,029,510	1.02	175,403
Tennessee	7,121,380	7,925,350	1.11	11,930
Texas	1,892,176	3,160,965	1.67	4,197
Utah	2,517,809	4,224,556	1.68	3,053
Virginia	6,507,997	5,877,486	.90	7,264
Washington	3,911,899	9,764,465	2.50	6,314
West Virginia	61,671,019	56,665,061	.92	68,663
Wyoming	7,533,088	11,706,187	1.55	7,771
Total bituminous †	417,111,142	469,281,719	1.12	555,533
Pennsylvania, anthracite	84,485,236	160,275,302	1.90	169,497
Grand total	501,596,378	629,557,021	1.25	725,030

* Short tons, 2000 lbs., are used in the government statistics; long or gross tons, 2240 lbs., are commonly used in the trade.

† Includes semi-bituminous, sub-bituminous, and lignite, and all anthracites except Pennsylvania.

COAL PRODUCTION OF THE UNITED STATES IN 1910.—*Continued.*

	Bituminous.	Anthracite.	Total.
Tons loaded at mines for shipment......	342,969,220	73,623,227	416,592,447
Sold to local trade and used by employees	12,286,851	2,020,572	14,307,423
Used at mines for steam and heat.......	9,667,621	8,841,437	18,509,058
Made into coke.....................	52,187,450	....	52,187,450
Total........................	417,111,142	84,485,236	501,596,378

To the value of coal at the mine, averaging $1.25 per ton according to the table on page 42, must be added the freight charge to obtain its cost to the consumer. If this charge averages $1.00 per ton, probably too low a figure, it makes the total cost of coal consumed in the United States over 1100 millions of dollars per annum.

The average number of days in the year in which the mines were active was 220; in the bituminous region 217, in the anthracite 229.

In several States in the Middle West the production of 1910 was much less than that of 1909 on account of a miners' strike of long duration. The States that showed a large decrease in 1910 gave the following tonnage in 1909:

Arkansas...........	2,377,157 tons	Michigan............	1,784,692 tons
Illinois.............	50,904,990 "	Missouri.............	3,756,530 "
Kansas.............	6,986,478 "	Oklahoma...........	3,119,377 "

PRODUCTION OF COAL IN THE UNITED STATES FROM 1820 TO 1910, IN SHORT TONS.

Year.	Pennsylvania Anthracite.	Bituminous.	Total.	Year.	Pennsylvania Anthracite.	Bituminous.	Total.
1820	450	3,000	3,450	1901	67,471,667	225,828,149	293,299,816
1830	215,272	104,800	320,072	1902	41,373,595	260,216,844	301,590,439
1840	967,108	1,102,931	2,070,039	1903	74,607,068	282,749,348	357,356,416
1850	4,138,164	2,880,017	7,018,181	1904	73,156,709	278,659,689	351,816,398
1860	8,115,842	6,494,200	14,610,042	1905	77,659,850	315,062,785	392,722,635
1870	15,664,275	17,371,305	33,035,580	1906	71,282,411	342,874,867	414,157,278
1880	28,649,812	42,831,758	71,481,570	1907	85,604,312	394,759,112	480,363,424
1885	38,335,974	72,824,321	111,160,295	1908	83,268,754	332,573,944	415,842,698
1890	46,468,641	111,302,322	157,770,963	1909	81,070,359	379,744,257	460,814,616
1895	57,999,337	135,118,193	193,117,530	1910	84,485,236	417,111,142	501,596,378
1900	57,367,915	212,316,112	269,684,027				

PRODUCTION OF COAL PER CAPITA IN THE UNITED STATES (MINERAL RESOURCES, 1910).

Year.................	1850	1860	1870	1880	1890	1900	1910
Short tons per capita....	0.278	0.514	0.96	1.52	2.52	3.53	5.45

The rate of increase in the production of anthracite is now not materially different from the rate of increase in population. An-

thracite is rapidly being supplanted by bituminous coal as a fuel for manufacturing purposes as its cost of production increases.

AVERAGE YEARLY PRODUCTION OF COAL IN THE UNITED STATES FOR EACH DECADE

Years.	Short Tons.	Years.	Short Tons.
1814–1845	864,913	1876–1885	84,776,032
1846–1855	8,341,783	1886–1895	158,609,864
1856–1865	17,379,502	1896–1905	283,240,275
1866–1875	41,942,511	1906–1910 (5 years)	454,554,879

WORLD'S PRODUCTION OF COAL (TOTAL ABOUT 1,300,000,000 SHORT TONS).

Country.	Year.	Short Tons.	Country.	Year.	Short Tons.
United States....	1910	501,596,378	Spain...........	1909	4,546,713
Great Britain....	1910	296,007,699	Transvaal.......	1910	4,446,477
Germany........	1910	245,043,120	Natal...........	1910	2,572,012
Austro-Hungary .	1909	54,573,788	New Zealand.....	1909	2,140,597
France..........	1910	42,516,232	Mexico..........	1909	1,432,990
Belgium........	1910	26,374,986	Holland.........	1909	1,235,515
Russia and Finland.......	1910	24,967,095	Queensland and Victoria.......	1909	1,119,708
Japan..........	1909	16,505,418	Italy...........	1909	611,857
India..........	1909	13,294,528	Sweden.........	1909	272,056
China..........	1909	13,227,600	Cape Colony.....	1909	103,519
Canada.........	1910	12,796,512	Tasmania........	1909	93,845
New South Wales.	1909	7,862,264	Other countries. ..	....	5,236,903

Formation of Coal.—According to the geologists a piece of coal was many thousands of years ago a mass of damp vegetable fibre, a portion of a peat-bog. Half of its weight, approximately, was water, and the other half would contain, by analysis, about 50% carbon, 6% hydrogen, 40% oxygen, 1% nitrogen, and 2% ash. During successive geologic ages the peat-bog was submerged and overlaid with mud, which hardened into slate. This was covered with glacial and alluvial drift, and it may have been tilted and upheaved by volcanic action or subsidence of the earth's crust. It was subjected to great pressure and high temperature, and underwent a more or less complete destructive distillation under pressure.

The conditions under which the distillation of the peat-bogs took place were not alike in different parts of the world. The variable factors were time, depth and porosity of the overlying strata, pressure and temperature, disturbance of the beds by floods and by intrusion

into them of minerals, such as carbonate of lime held in solution, or clay, sand, iron, and sulphur. Therefore the product of the distillation varies in different locations all the way from the original peat through brown coal or lignite, bituminous and semi-bituminous coal, semi-anthracite and anthracite, to graphitic coal. The last-named, which is found in Rhode Island, has nearly all the volatile hydrocarbon gases and oxygen driven off from it, leaving practically only fixed carbon and ash, the carbon being in a form which is so hard to burn that the coal is not used as a commercial fuel; while the first, lignite, is only one remove from the peat or woody fibre, retaining perhaps a third of the water, and a large part of the original hydrocarbon, or rather oxy-hydrocarbon, since it contains a large percentage of oxygen. The progresive change in chemical analysis, from wood to coal, is shown in the two following tables:

DIMINUTION OF H AND O IN SERIES FROM WOOD TO ANTHRACITE.*

Substance.	Carbon.	Hydrogen.	Oxygen.
Woody fibre	52.65	5.25	42.10
Peat from Vulcaire	59.57	5.96	34.47
Lignite from Cologne	66.04	5.27	28.69
Earthy brown coal	73.18	5.58	21.14
Coal from Belestat, secondary	75.06	5.84	19.10
Coal from Rive de Gier	89.29	5.05	5.66
Anthracite, Mayenne, transition formation	91.58	3.96	4.46

* Groves and Thorpe's Chemical Technology, vol. i. Fuels, p. 58.

PROGRESSIVE CHANGE FROM WOOD TO GRAPHITE.†

	Wood.	Loss.	Lignite.	Loss.	Bit. coal.	Loss.	Anthracite.	Loss.	Graphite.
Carbon	49.1	18.65	30.45	12.35	18.10	3.57	14.53	1.42	13.11
Hydrogen	6.3	3.25	3.05	1.85	1.20	0.93	0.27	0.14	0.13
Oxygen	44.6	24.40	20.20	18.13	2.07	1.32	0.65	0.65	0.00
	100.0	46.30	53.70	32.33	21.37	5.82	15.45	2.21	13.24

† J. S. Newberry in Johnson's Cyclopedia.

We thus have different varieties of coal, due to differences in the extent to which the volatile gases have been driven off from the original neat or other woody coal-forming substance. There are also differences in quality in each variety, due to varying percentages of ash and water. The ash, or earthy matter, in coal ranges from 2 to

over 30% in different localities. The water ranges from less than 1% in the anthracites up to 14% or more in some Illinois coals and to 25% or more in some lignites. This water seems to be held by capillary attraction, or some similar force, within the particles of a piece of apparently dry coal, so that it cannot all be driven off without heating it to a temperature considerably higher than 212° F., say 250° to 280° F. The bituminous coals are hygroscopic, like wood;* that is, they absorb moisture from the atmosphere, and the quantity they will contain depends not only on the nature of the coal, but on the relative humidity of the atmosphere, which changes from day to day.

Classification of Coal.—It is convenient to classify the several varieties of coal according to the relative percentages of carbon and volatile mater contained in their combustible portion as determined by proximate analysis. The following is such a classification:†

	Fixed Carbon.	Volatile Matter.	Heating Value per Lb. Combustible.	Relative Value of Combustible Semi-bit. = 100.
Anthracite..........	97 to 90	3 to 10	14,800 to 15,400	93
Semi-anthracite.....	90 to 85	10 to 15	15,400 to 15,500	97
Semi-bituminous....	85 to 70	15 to 30	15,400 to 16,000	100
Bituminous, Eastern.	70 to 55	30 to 45	14,800 to 15,600	96
" Western.	65 to 50	35 to 50	12,500 to 14,800	90
Lignite.............	under 50	over 50	11,000 to 13,500	77

The locations in which the several classes of coal are found are destribed in some detail in the chapter on Coal-fields of the United States. The anthracites, with some unimportant exceptions, are con-

* Note on the Hygroscopicity of Wood (from Johnson's Materials of Construction, p. 224).—Kept on a shelf in an ordinary dwelling, wood still retains 8 to 10% of its weight of water. Nor is the amount of water in dry wood constant; the weight of a panful of shavings varies with the time of day, being on a summer day greatest in the morning and least in the afternoon.

Desiccating the air with chemicals will cause the wood to dry, but wood thus dried at 80° F. will still lose water in the kiln. Wood dried at 120° F. loses water still if dried at 200° F., and this again will lose more water if the temperature is raised. Absolutely dry wood cannot be obtained; chemical destruction sets in before all water is driven off.

On removal from the kiln the wood at once takes up water from the air, even in the driest weather. At first the absorption is quite rapid; at the end of a week a short piece of pine, 1½ in. thick, has regained two-thirds of, and in a few months all, the moisture it has when air-dry, 8 to 10%, and also its former dimensions.

† A more satisfactory classification will be found on page 58.

fined to three small fields in eastern Pennsylvania. The semi-anthracites are found in a few small areas in the western part of the anthracite field. The semi-bituminous coals are found in a narrow strip of territory, 20 miles wide or less, on the eastern border of the great Appalachian coalfield, extending from north-central Pennsylvania across the southern boundary of Virginia into Tennessee, a distance of over 300 miles.

It is a peculiarity of these semi-bituminous coals that their combustible portion is of remarkably uniform composition, the volatile matter usually ranging between 18 and 22 per cent of the combustible, and approaching in its anaylsis marsh-gas, CH_4, with very little oxygen. They are usually low also in moisture, ash, and sulphur, and rank among the best steam-coals in the world. The eastern bituminous coals occupy the remainder of the Appalachian coal-field, from Pennsylvania and eastern Ohio to Alabama. They are higher in volatile matter, ranging from 30 to over 40 per cent, the higher figures in the western portion of the field. The volatile matter is of lower heating value, being higher in oxygen. The Western bituminous coals and lignites are found in most of the States west of Ohio. They are higher in volatile matter and in oxygen and moisture than the bituminous coals of the Appalachian field, and usually give off a denser smoke when burned in ordinary furnaces.

The U. S. Geological Survey recognizes six classes of coal. They are described as follows by Prof. N. W. Lord (*Power*), Aug. 18, 1908):

(1) Anthracite, (2) semi-anthracite, (3) semi-bituminous, (4) bituminous, (5) sub-bituminous or black lignite, and (6) lignite. While this classification is generally useful, it is difficult to draw fast and sharp lines in the classification, as samples are found on the border lines of almost any system of classification. The general qualities of these types of fuel correspond well to the coals of certain regions, as the anthracites of Pennsylvania, the coking bituminous coals of Pennsylvania, the non-coking bituminous coals of Ohio and Illinois. Coals differ widely not only in their physical characteristics, their behavior under a destructive distillation, some cementing together into a hard coke or possessing the coking property, as it is termed, others, the so-called dry coals, showing but little or none of this quality, but also in their chemical composition and in their associated impurities.

The proximate analysis of coal is merely a record of the nature of the decomposition that the coal undergoes when treated in a certain

conventional manner. It involves the determination of the moisture or loss in weight when the coal is dried under certain specific conditions; of the volatile combustible matter or the material other than moisture which is driven off by heating the coal in a prescribed way in a platinum crucible; the fixed carbon, which is the loss in weight of the residue after driving out the volatile matter when the combustible matter is all burned out by heating in air; and, finally, the ash or combustible residue left from the foregoing treatment.

In the ultimate analysis of the coal the actual percentages of carbon, hydrogen, nitrogen, sulphur, oxygen and incombustible residue or ash are determined. The heating value of a coal is the amount of heat expressed in British thermal units developed by the complete combustion of one pound of the coal, and for all purposes in which coal is used as a fuel is, of course, the fundamental factor on which the fuel value of the material is based. The following table gives

COMPOSITION OF ILLUSTRATIVE COALS.

	Class.	1	2	3	4	5	6	7
Proximate analysis.*	Moisture	2.08	1.28	0.65	0.97	7.55	8.68	9.88
	Volatile combustible	7.27	12.82	18.80	29.09	34.03	41.31	36.17
	Fixed carbon	74.32	73.69	75.92	60.85	52.57	46.49	43.65
	Ash	16.33	12.21	4.63	9.09	5.85	3.52	10.30
	Loss in air drying	3.40	1.10	1.10	4.20	Undet.	11.30	23.50
Ultimate analysis.†	Hydrogen	2.63	3.63	4.54	4.57	5.06	5.31	4.47
	Carbon	76.86	78.32	86.47	77.10	75.82	73.31	64.84
	Oxygen	2.27	2.25	2.68	6.67	10.47	15.72	16.52
	Nitrogen	0.82	1.41	1.08	1.58	1.50	1.21	1.30
	Sulphur	0.78	2.03	0.57	0.90	0.82	0.60	1.44
	Ash	16.64	12.36	4.66	9.18	6.33	3.85	11.43
*	Calorific value in B.T.U.	12,472	13,406	15,190	13,951	12,510	11,620	10,288

* Air-dried sample. † Coal-dried at 105° C.

RESULTS CALCULATED TO ASH AND MOISTURE-FREE BASIS.

Proximate.	Volatile combustible	8.91	14.82	19.85	32.34	39.30	47.05	45.31
	Fixed carbon	91.09	85.18	80.15	67.66	60.70	52.95	54.69
Ultimate.	Hydrogen	3.16	4.14	4.76	5.03	5.41	5.50	5.05
	Carbon	92.20	89.36	90.70	84.89	80.93	76.35	73.21
	Oxygen	2.72	2.57	2.81	7.34	11.18	16.28	18.65
	Nitrogen	0.98	1.61	1.13	1.74	1.61	1.25	1.47
	Sulphur	0.94	2.32	0.60	1.00	0.87	0.62	1.62
	Calorific value in B.T.U.	15,281	15,496	15,744	15,512	14,446	13,203	12,889

the proximate and ultimate analyses and the heating value of a typical coal in each of the foregoing six classes. The coals given in the table are:

1. Anthracite, culm, Scranton, Penn. 2. Semi-anthracite, Coalhill, Ark. 3. Semi-bituminous, Mora, W. Va. 4. Bituminous coking, near Connellsville, Penn. 5. Bituminous non-coking, Ohio No. 6, Hocking Valley. 6. Sub-bituminous, black lignite, Uinta County, Wyoming. 7. Lignite, Milan County, Texas.*

It will be seen that there is a progressive change, consisting of a decrease in the fixed carbon and increase in the volatile matter, and in the ultimate analysis, an increase in the amount of oxygen and hydrogen. The maximum heating value rests with the semi-bituminous coals of the Pocahontas type, high in fixed carbon and comparatively low in volatile matter. The amount of moisture varies with the type of coal, but only in a very general way. Coals freshly mined contain considerable water, which is rapidly lost on exposure to air. The analyses are reported upon the coal in approximately the condition of moisture to which it will attain upon standing exposed to the ordinary air, the coal being in a coarsely crushed condition. If the coal be considered as made up of three main constituents: moisture, the combustible portion or true coal, and the ash, the typical analyses of the various groups may be corrected by eliminating by calculation the amount of moisture and ash and restating the composition of the remainder considered as coal. This is done in the latter part of the table.

With the analyses thus given the progressive changes in the composition become much more apparent and uniform, particularly the progressive increase in volatile matter and decrease in fixed carbon. The heating value of the combustible portion is highest in the semi-bituminous, class 3.

The sulphur in the coal may be regarded as one of its impurities, though in many cases a considerable portion of it is an inherent part of the coal proper, only a portion of it existing as iron pyrites. In

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* The coal classed as anthracite in the above table, No. 1, is higher in volatile matter than most of the Pennsylvania anthracites. In some early classifications it would be called a semi-anthracite. The two bituminous coals 4*a* and 4*b* differ more both in composition and in heating value than the sub-bituminous, No. 5, coal and the lignite, No. 6. It is evident that in any system of classification, one class will overlap another, and no strict lines of division can be drawn between the several classes.

many coals, on the contrary, a large percentage of the sulphur present is simply mechanically mixed pyrites. The foregoing outline serves to show that the coal from any district or mine may be considered as made up of coal proper and a certain amount of mechanically held impurities, consisting of ash, moisture, and sulphur in the form of pyrites.

The character of the coal proper is much less subject to variation in the mines of a given seam in a given district than are the relative proportions of the impurities, particularly ash and sulphur, which vary greatly in different portions of the same seam and frequently vary considerably from one portion of a field to the other. An interesting example of this is found in the Middle Kittanning coal, of the Ohio series, in which the sulphur in certain portions of the seam covering areas of many square miles in extent will run under 1 per cent, the amount increasing, however, as the seam extends northward until regions are reached where for the same coal the average sulphur content is over 5 per cent. Variations in the ash take place in the same way.

Caking and Non-caking Coals.—Bituminous coals are sometimes classified as caking and non-caking coals, according to their behavior when subjected to the process of coking. The former undergo an incipient fusion or softening when heated, so that the fragments coalesce and yield a compact coke, while the latter (also called free-burning) preserve their form, producing a coke which is only serviceable when made from large pieces of coal, the smaller pieces being incoherent. The reason of this difference is not clearly made out, as non-caking coals are often of very similar ultimate chemical composition to those in which the caking property is very highly developed. It is found that caking coals lose that property when exposed to the air for a lengthened period, or by heating to about 570° F., and that the dust or slack of non-caking coal may, in some instances, be converted into a coherent cake by exposing it suddenly to a very high temperature. Some coals which cannot be made into coke in the beehive ovens are easily choked in modern gas-heated ovens.*

Long-flaming and Short-flaming Coals.—The distinction between long-flaming and short-flaming coals is one commonly made by European writers, but it is not often made in this country. A long-

* For a discussion of the relation of the chemical composition to the coking property see Bulletin 29 of the U. S. Bureau of Mines, 1911, The Effect of Oxygen in Coal, by David White.

flaming coal is simply one having a high percentage of volatile matter, and which gives off a long flame when burned in an ordinary furnace on account of the difficulty of supplying the volatile matter with a sufficient quantity of hot air to cause its complete combustion. The same coal will give a short flame when burned in an underfeed stoker furnace with an adequate supply of air.

Bituminous Coal contains no Bitumen.—The solvents for bituminous substances, such as bisulphide of carbon and benzole, have no effect upon bituminous coals.

J. C. W. Frazer and E. J. Hoffman (Technical Paper No. 5, of the Bureau of Mines, 1912) obtained a tarry substance amounting to nearly 11 per cent of the original weight, by extracting an Illinois coal with phenol. This was separated by treatment with various solvents into a great number of other substances, some of which appear to approach pure compounds. Pyridin and anilin have also been used to extract soluble constituents from coal. The investigation is incomplete.

Cannel-coals are bituminous coals that are higher in hydrogen than ordinary coals. They are valuable as "enrichers" in gas-making.

ULTIMATE ANALYSIS OF SOME CANNEL-COALS.

						Combustible.		
	C.	H.	O+N.	S.	Ash.	C.	H.	O+N
Boghead, Scotland...	63.10	8.91	7.25	0.96	19.78	79.61	11.24	9.15
Albertite, Nova Scotia	82.67	9.14	8.19	....	.....	82.67	9.14	8.19
Tasmanite, Tasmania	79.34	10.41	4.93	5.32	.....	83.80	10.99	5.21
LIGNITE OR BROWN COAL (HIGH IN OXYGEN).								
Cologne...........	63.29	4.98	26.24	....	8.49	66.97	5.27	27.76
Bovey, Devonshire..	66.31	5.63	23.43	2.36	2.36	69.53	5.90	24.57
Trifail, Styria.......	50.72	5.34	35.98	0.90	7.86	55.11	5.80	39.09

The above analyses do not give the water or hygroscopic moisture.

Sub-bituminous Coal and Lignite.—The term lignite is commonly given to all the coals which are intermediate in properties between peat and the coals of the older formations. They are characterized by high moisture and oxygen, and are therefore lower in heating value than bituminous coal. The names "black lignite," "brown lignite," "brown coal," and "lignitic coal" have also been given indiscriminately to all these coals. The U. S. Geological Survey divides them into two varieties, sub-bituminous coal and lignite. They are thus distin-

guished: sub-bituminous coal is black or grayish black in color; is high in moisture, which is given off readily on exposure to sun or air, producing "weathering" or "slacking"; has no distinct system of joints, but has a tendency to separate on weathering into thin plates parallel to the bedding. The fresh coal has a bright luster and an irregular conchoidal fracture; the resulting fragments are lusterless and their surfaces do not show an even fracture of any kind. Certain sub-bituminous coals have high heating value and will stand transportation in closed cars without slacking, but will check slightly when exposed to the rays of the sun in open cars.

Lignite is brown in color or has a distinctly brownish cast. The texture is more or less distinctly woody, although some lignite, notably that of Texas, is amorphous. The amount of moisture is greater than that of sub-bituminous coal, and ranges from 25 to nearly 45 per cent.

Decrease of Weight of Lignite in Transit. (A. C. Scott, *Power,* May 11, 1909.)—Contention between shippers and consumers of lignite concerning shortage in weights of carloads delivered is in many instances due to misunderstandings, first, as to the necessary decrease in weight that must occur in transit due to the properties of the lignite and, second, as to the fact that a smaller weight of lignite at the consumer's plant as compared with the weight at the mine does not necessarily mean that the consumer has lost money in proportion to the shortage; on the contrary, the consumer is actually the gainer in the transaction, provided the loss in weight is not abnormal.

Three samples of lignite were taken from a mine and tested for moisture immediately after the jars were opened, with the following results:

No. 1, 28.2%; No. 2, 28.0%; No. 3, 32.2%.

A lump of the lignite was soaked for 24 hours in water, and subsequently a test showed 39.1% moisture. This indicates that, taking the average moisture content of the three samples at 29.4%, it is possible for the lignite to contain 9.7% more moisture than it does contain after it is taken directly from the mine, under the general conditions of this particular mine.

Sample No. 2, containing 28.2% moisture, when tested in a calorimeter, showed 7574 B.T.U. per lb. The average B.T.U. of the three samples, when a portion was dried at 104 to 107°C. for one hour, was 11,003 per lb.

Loss by Air Drying.—A portion of each of the three samples was placed in a tin box, open at the top, and the boxes placed in the thermometer and hygrometer house of the meteorological station at the University of Texas. Each sample was weighed twice a day for several days, and once a day thereafter for nearly two weeks, a record

of temperature and humidity of the air being kept by means of recording instruments placed close to the samples.

The lignite which was exposed in the three samples consisted of lump and moderately fine material which was intended to be as nearly as possible an average of the quality of the coal as loaded upon the cars. The percentage of loss of each of the samples was found to be very nearly the same as on the remaining lignite. An average is given in the following table of the loss for the three samples. The table also gives the average humidity and the temperature corresponding for the day when readings were taken and the percentage of loss calculated:

No.	Humidity.	Temp., °F.	Loss, %	No.	Humidity.	Temp., ° F.	Loss, %
1	83	75	2.47	7	82	75	11.11
2	84	77	4.73	8	67	71	12.58
3	93	68	6.94	9	59	67	15.76
4	95	66	6.72	10	69	69	18.52
5	83	70	8.15	11	69	67	19.48
6	77	74	9.51	12	59	63	20.61

The table shows that on the fourth day of the test there was a slight gain in moisture over that of the day previous, but this is due, without doubt, to the high humidity, the average being 95 for that day.

After exposure to the air for twelve days, during which time the average loss was 20.6%, determinations were made of heat values, and an average of 9964 B.T.U. per pound obtained.

Mr. Scott concludes that the loss in weight of lignite in transit is due largely, if not entirely, to loss of moisture by air-drying, and that the lignite received after partial air-drying is more valuable than when it was loaded at the mine.

Ash.—The composition of ash approximates to that of fire-clay, with the addition of ferric oxide, sulphate of lime, magnesia, potash, and phosphoric acid.

White-ash coals are generally freer from sulphur than the red-ash coals, which contain iron pyrites, but there are exceptions to this rule, as in a coal from Peru which contains more than 10% of sulphur and yields not a small percentage of white ash. In it the sulphur occurs in organic combination, but it is so firmly held that it can only be partially expelled, even by exposure to a very high heating out of contact with the air.

The fusibility of ash varies according to its composition. It is the more infusible the more nearly its composition approaches to fire-clay, or silicate of alumina, and becomes more fusible with the addition of

other substances, such as iron, lime, etc. Coals high in sulphur usually give a very fusible ash, on account of the iron with which the sulphur is in combination. A fusible ash tends to form clinker upon the grate-bars, and therefore is objectionable.

The amount of ash in coal varies greatly, ranging from less than 2 per cent to 30 per cent or more. It varies with the district in which the coal is mined, with individual mines of the district, with parts of the same mine, and with the care taken in mining. With anthracite coals it depends on the size, the larger sizes having the least ash.

Analyses of Coal Ash.—Complete analyses of ash of 58 samples of Illinois coal are given by Parr and Wheeler, together with the volatile inorganic matter, (carbon dioxide and chlorine) in the dry coal which is not found in the ordinary analysis for ash. The ash, found by the usual method, ranged from 7.53 to 16.25; CO_2 in the dry coal 0 to 2.48; Cl, 0 to 0.56 per cent. The mineral constituents of the ash, as obtained by high fusion, ranged as follows: SiO_2, 22.8 to 59.9; Fe_2O_3, 3.1 to 52.3; Al_2O_3, 3.2 to 31.5; CaO, 1.9 to 34.0; MgO, 0 to 2.0.

Heating Value of Coal.—The heating value of different varieties of coal, together with the relation of the heating value to chemical composition, will be treated at length in the chapter on Heating Value of Coal, but a brief statement of the subject is given below, copied from an article by the author in "Mines and Minerals," October, 1898.

Coal is composed of four different things, which may be separated by proximate analysis, viz., fixed carbon, volatile hydrocarbon, ash, and moisture. In making a proximate analysis of a weighed quantity, such as a gram of coal, the moisture is first driven off by heating it to 250° or 280° F., then the volatile matter is driven off by heating it in a closed crucible to a red heat, then the carbon is burned out of the remaining coke to a white heat, with sufficient air supply, until nothing is left but the ash.

The fixed carbon has a constant heating value of about 14,600 B.T.U. per lb. The value of the volatile hydrocarbon depends on its composition, and that depends chiefly on the district in which the coal is mined. It may be as high as 21,000 B.T.U. per lb., or about the heating value of marsh-gas, in the best semi-bituminous coals, which contain very small percentages of oxygen, or as low as 10,000 B.T.U. per lb., as in those from some of the Western States, which are high in oxygen. The ash has no heating value, and the moisture has in effect less than none, for its evaporation and the superheating of

the steam made from it to the temperature of the chimney-gases absorb some of the heat generated by the combustion of the fixed carbon and volatile matter.

The analysis of a coal may be reported in three different forms, as percentages of the moist coal, of the dry coal, or of the combustible. Thus, suppose one gram of coal is analyzed, and the first heating shows a loss of weight of 0.1 gram, the second of 0.3 gram, the third 0.5 gram, the remainder, or ash, weighing 0.1 gram, the complete report would be as follows:

	Per Cent of the Moist Coal.	Per Cent of the Dry Coal.	Per Cent of the Combustible.
Moisture	10		
Volatile matter	30	33.33	37.50
Fixed carbon	50	55.56	62.50
Ash	10	11.11	
	100	100.00	100.00

The relation of the volatile matter and of the fixed carbon in the last column of the table enables us to judge the class to which the coal belongs, as anthracite, semi-anthracite, semi-bituminous, bituminous, or lignite. Coals containing less than 10 per cent volatile matter in the combustible would be classed as anthracite, between 10 and 15 per cent as semi-anthracite, between 15 and 30 per cent as semi-bituminous, between 30 and 50 per cent as bituminous, and over 50 per cent as lignitic coals or lignites.

The figures in the second column, representing the percentages in the dry coal, are useful in comparing different lots of coal of one class, and they are better for this purpose than the figures in the first column, for the moisture is a variable constituent, depending to a large extent on the weather to which the coal has been subjected since it was mined, on the amount of moisture in the atmosphere at the time when it is analyzed, and on the extent to which it may have accidentally been dried during the process of sampling.

The heating value of a coal depends on its percentage of total combustible matter, and on the heating value per pound of that combustible. The latter differs in different districts and bears a relation to the percentage of volatile matter. It is highest in the semi-bituminous coals, being nearly constant at about 15,750 B.T.U. per lb. It is between 14,800 and 15,500 B.T.U. in anthracite, and ranges from

15,500 down to 13,000 or less in the bituminous coals, decreasing usually as we go westward, and as the volatile matter contains an increasing percentage of oxygen.

In 1892 the author deduced from Mahler's tests on European coals a table of the approximate heating value of coals of different composition, which is given, somewhat modified, below. (Trans. A. S. M. E., vol. xx. p. 337.)

APPROXIMATE HEATING VALUE OF COALS.*

Per Cent Volatile Matter in Coal Dry and Free from Ash.	Heating Value per Lb. Combustible.		Per Cent Volatile Matter in Coal Dry and Free from Ash.	Heating Value per Lb. Combustible.	
	B.T.U.	Calories.		B.T.U.	Calories.
0	14,580	8,100	32	15,480	8,600
3	14,940	8,300	37	15,120	8,400
6	15,210	8,450	40	14,760	8,200
10	15,480	8,600	43	14,220	7,900
13	15,660	8,700	45	13,860	7,700
20	15,840	8,800	47	13,320	7,400
28	15,660	8,700	49	12,420	6,900

* See the curve plotted from these figures on page 159.

The experiments of Lord and Haas on American coals (Trans, Am. Inst. Mining Engineers, 1897) practically confirm these figures for all coals in which the percentage of volatile matter is less than 40% of the combustible, but for coals containing less than 60% fixed carbon or more than 40% volatile matter in the combustible they are liable to an error in either direction of about 4%. It appears from these experiments that the coal of one seam in a given district, where the ratio of the volatile matter to the total combustible is uniform, has the same heating value per pound of combustible, within one or two per cent, but that coals of the same proximate analysis, and containing over 40% volatile matter, but mined in different districts, may differ 6 or 8 per cent in heating value.

It will be noticed that the coals containing from 13 to 28 per cent of volatile matter in the combustible have practically the same heating value. This is confirmed by Lord and Haas's tests of Pocahontas coal. A study of these tests and of Mahler's indicates that the heating value of all the semi-bituminous coals, 15 to 30 per cent volatile matter, is within 1½% of 15,750 B.T.U. per lb.

The heating value of any coal may also be calculated from its ulti-

mate analysis, with a probable error not exceeding 2% (except in the cases of cannel-coal and some lignites, in which the error may be greater) by the following formula:

$$\text{Heating value per lb.} = 146C + 620\left(H - \frac{O}{8}\right),$$

in which C, H, and O are respectively the percentages of carbon, hydrogen, and oxygen. This formula is known as Dulong's. Its approximate accuracy is proved by both Mahler's and Lord and Haas's experiments, and any deviation of the calorimetric determination of any ordinary coal more than 2% from that calculated by the formula is more likely to proceed from an error in either the calorimetric test or the analysis than from an error in the formula.

Goutal's Formula.—E. Goutal, in *Comptes Rendus*, Sept., 1902, gives a formula which is frequently quoted by other writers, in English units, as follows: B.T.U. $= 14{,}760\ C + aV$, in which C is the fixed carbon and V the volatile matter in 1 lb. of combustible, and a a coefficient taken from a table. (See Gebhardt's Power Plant Engineering.) The values obtained by this formula agree fairly well with those given in the author's table for coals in which the volatile matter is not in excess of 30% of the combustible; beyond that they vary considerably. It is evident that it is easier to take the B.T.U. directly from a table than to find the value of a in a table and then to make the computation from a formula.

W. Inchley (*The Engineer*, Feb. 17, 1911), gives a formula which he considers better than Dulong's for steam coal, viz.:

$$\begin{aligned}\text{Calorific value} &= 8{,}000C + 33{,}830H \text{ calories per gram.}\\ &= 14{,}400C + 60{,}890H \text{ B.T.U. per lb.}\end{aligned}$$

It is evident, since his formula contains no factor for oxygen, that it cannot give correct results for coals high in oxygen. Testing it by the average figures given by Lord and Haas for Pocahontas and Hocking Valley coals (see pages 156 and 157) we find the following:

	By Calorimeter	Dulong	Inchley.
Pocahontas..........	8176	8198	8241
Hocking Valley.......	6663	6683	6892

Errors in Reported Heating Values of Coals.—Errors in sampling and in the calorimetric test are quite common, and the error of the latter is almost always in the direction of making the reported heat-

ing value of a coal too small. The effect of this error is to make the apparent efficiency of a boiler tested with this coal higher than the real efficiency. Whenever the efficiency reported is high and at the same time the reported heating value of the fuel per pound of combustible is more than 2 per cent lower than the average figures in published tables for coal from the same district, the results should be looked on with suspicion. Further information on this subject will be found in a paper by the author entitled "The Efficiency of a Steam-boiler: What is it?" in Trans. Am. Soc. Mechanical Engineers, vol. xvii, p. 645.

New Classification, and Tables of Heating Value.*—The recent publication by the United States Bureau of Mines in Bulletin No. 22 of over 3000 analyses and results of calorimetric examinations of American coals offers the best opportunity that has ever been had for a study of the long-mooted questions of the classifications of coals and of the relation of their chemical composition to their heating value.

The writer has made a selection of 155 analyses of coals from different states, showing practically the extreme range of composition of heating value of the coals of each of these states, whenever a sufficient number of coals of such states are given in the bulletin. The most important items of the ultimate and proximate analyses were tabulated, viz., the S, H, C, O, and N of the ultimate analysis as referred to the combustible (coal free of moisture and ash), also the volatile matter, the moisture and the ash of the proximate analysis, the moisture and ash being referred to the coal as received, and the volatile matter being referred to the combustible. (See Table I.) The fixed carbon referred to combustible is 100 per cent minus the volatile matter of the combustible, and referred to coal as received it is 100 per cent minus the sum of moisture ash and volatile matter. The results as given in the bulletin were calculated to three different bases: (1) as received, (2) dry coal, (3) ash and moisture free (commonly called combustible); and in many cases to a fourth basis, ash, moisture, and sulphur-free. For the purpose of comparison, however, other information was desired, such as the B.T.U. per lb. of coal air-dry, ash-free, and air-dry, ash- and sulphur-free, not contained in the bulletin. The writer has calculated and tabulated these omitted items, but it should be stated that the figures which he ob-

* Abstract of a paper presented by the author at the June, 1914, meeting of the American Society of Mechanical Engineers.

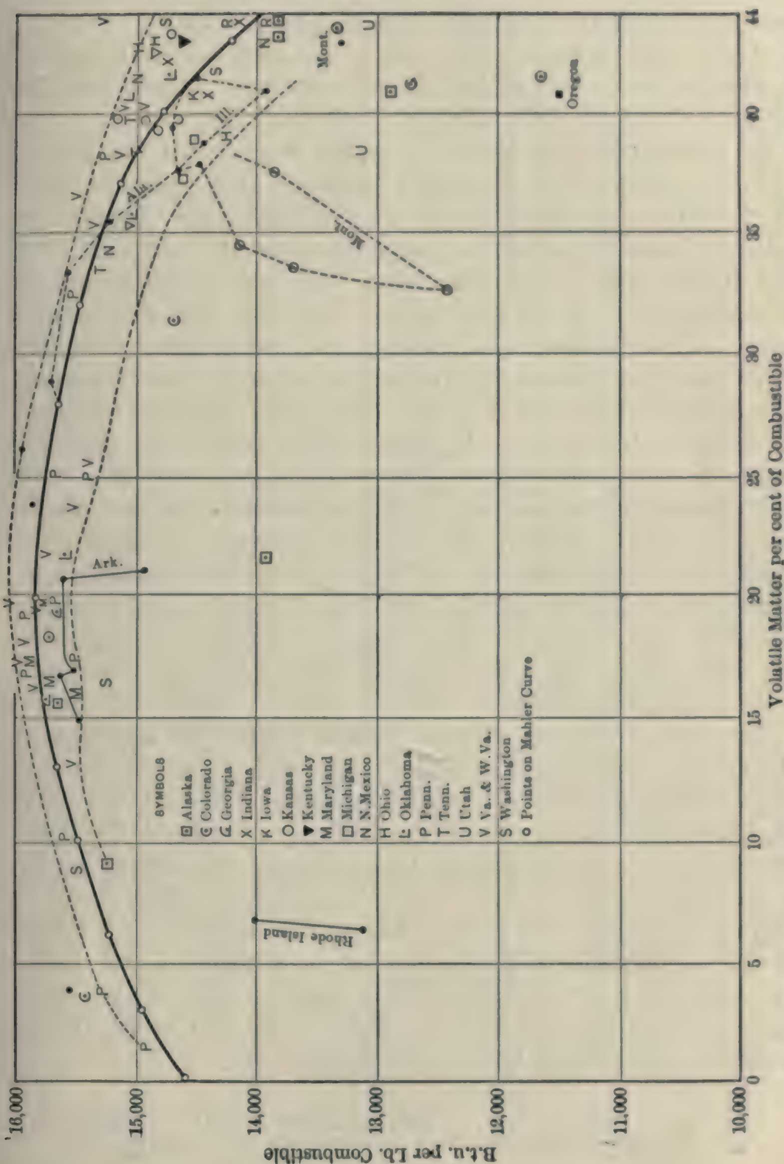

FIG. 2.—RELATION OF HEATING VALUE TO PERCENTAGE OF VOLATILE MATTER IN THE COMBUSTIBLE.

tained relating to B.T.U. calculated to the sulphur-free basis, are probably too high in many cases of high sulphur coals.

Having thus tabulated the results, the questions to be solved are (1) how shall the coals be classified; (2) what relation does the heating value of the coals bear to the chemical composition.

In studying the 155 coals, the writer first plotted the B.T.U. per lb. combustible with the results which are shown graphically in Fig. 2. This plotting shows that all the coals of the Appalachian field come close to the original curve drawn by the writer in 1892 from Mahler's tests of European coals, when the volatile matter in the combustible is 35 per cent or less. For coals higher in volatile matter, and for Western coals generally, the heating value varies over a wide range and appears to have no relation to the volatile matter, but each district has a law of its own. The Illinois coals are all found within the small area shown by dotted lines. Perhaps the most important conclusion from Fig. 2 is that all the semi-bituminous coals of the Eastern states, and those from the Western states and Alaska with a very few exceptions, have a heating value per pound of combustible that is very close to 15,750 B.T.U. With bituminous coals and lignite containing over 36 per cent of volatile matter in the combustible there appears to be no law connecting the heating value with the percentage of volatile matter, and the plotting is not continued beyond 44 per cent.

As many of the coals high in volatile matter are also high in sulphur, it was attempted to find if high sulphur was the cause of some of the variation of the heating value, but the results are negative. When the heating value per pound of combustible is converted for sulphur by the usual method, by subtracting 4050 B.T.U. per lb. S, and dividing by 1 minus (% S÷100), the value thus found is often far higher than the heating value per pound of combustible of coals of the same districts that are low in sulphur. Lower values for these coals might be found if they were converted by the "unit coal" method of Parr and Wheeler (Bulletin 37, 1909, of the Illinois University Engineering Experiment Station), viz.:

$$\text{B.T.U. per lb. unit coal} = \frac{\text{Indicated dry B.T.U.} - 5000\text{S}}{1.00 - (1.08\ \text{ash} + 0.55\text{S})}.$$

Fig. 3 shows the result of plotting the heating value per pound of air-dry coal and ash- and sulphur-free, against the percentage of

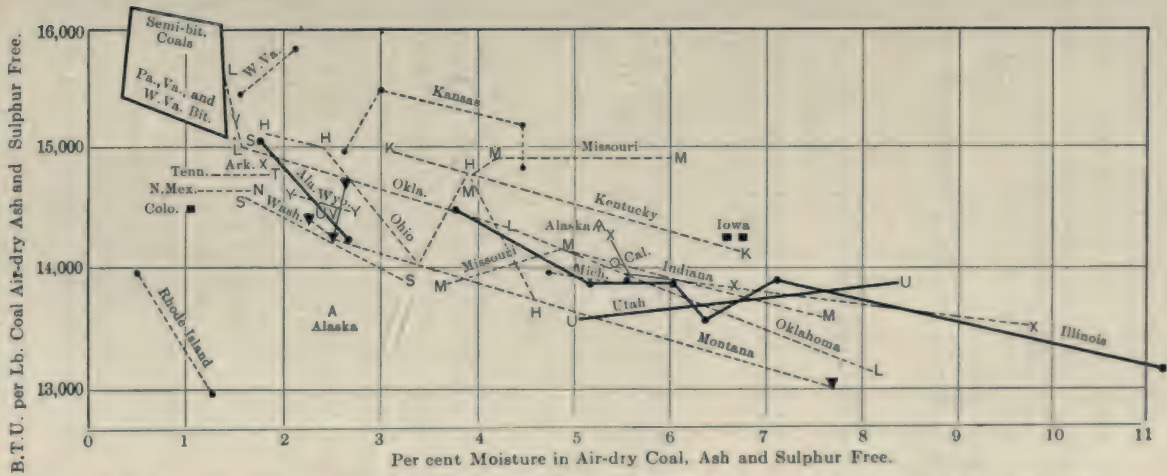

FIG. 3.—RELATION OF HEATING VALUE TO MOISTURE IN AIR-DRY COAL, ASH AND SULPHUR FREE.

moisture in such coal, for those cases in which the moisture does not exceed 11 per cent. The results indicate that this method may prove to be of considerable importance when it is applied separately to the coals of different states or districts, especially the bituminous coals of the Middle West. The high position of the Kansas coals and of one of the Missouri coals may be due to the error of the common method of correcting for sulphur.

The average results shown in Fig. 3 correspond approximately to the following formula.

$$\text{B.T.U. per lb. air-dry coal, ash-free} = 16{,}400 - 800M_a, \text{ for semi-bituminous coal;}$$

$$= 15{,}300 - 240M_a, \text{ for bituminous coal;}$$

in which M_a is the percentage of moisture remaining in the coal after air-drying, referred to the coal free from ash. That is,

$$M_a = \frac{M - L}{100 - (A + L)},$$

in which M and A are respectively the moisture and ash in the coal as received, and L is the loss on air-drying, figured as a percentage of the coal as received.

After studying the coals by the method of plotting as described, Table 2 was constructed, in which a revised classification is attempted. The extreme differences in B.T.U. per lb. between the B.T.U. per lb. given and those that result from calculation by Dulong 's formula, by the Mahler curve, and by the moisture formulæ for air-dry, ash-free coal, are given in the table on page 73. The extent of these differences suggests that in some cases the calorimetric determinations, or the analyses, or both, may be in error, and indicates the necessity for thoroughly checking the loss in air-drying, the moisture determinations of the air-dried coal, the analyses, proximate and ultimate, and the calorimetric work.

TABLE I.

ANALYSES AND HEATING VALUES.

Page of Bulletin 22.	Volatile Matter, % of Combustible	Composition of the Combustible.					B.T.U. per lb. Combustible	As Received.				Air Dry, Ash Free.		
		S	H	C	N	O		M Moist.	L Loss on Air Drying.	A Ash.	B.T.U.	$F=100-(A+L)$	$\frac{\text{B.T.U.}}{F}=\text{B.T.U.}$	$\frac{M-L}{F}=M_1$
							ALABAMA.							
36	28.8	0.59	5.32	88.05	1.59	4.45	15,757	3.08	2.0	3.75	14,681	94.25	15,577	1.15
37	27.9	1.58	5.28	88.07	1.65	3.42	15,620	2.38	1.5	4.88	14,487	93.62	15,475	0.94
38	33.4	1.13	4.99	85.09	1.80	6.99	15,590	2.18	1.0	2.79	14,816	96.21	15,400	1.23
39	35.3	1.07	5.36	85.18	1.39	7.00	15,214	3.83	2.2	5.48	13,799	92.32	14,947	1.77
41	37.7	1.37	5.07	81.28	1.83	10.45	14,467	3.95	1.7	14.59	11,785	83.71	14,078	2.69
							ALASKA.							
41	44.2	1.83	5.70	77.50	0.86	14.11	13,838	7.06	5.2	21.78	9,846	73.02	13,484	2.55
41	40.8	0.94	5.09	74.32	0.82	18.83	12,964	10.77	6.5	14.87	9,641	78.63	12,261	5.42
41	15.5	1.29	4.37	89.78	1.54	3.02	15,651	5.14	4.6	5.00	14,065	90.40	15,559	0.60
42	8.8	0.73	3.68	89.63	1.92	4.04	15,203	7.43	6.2	14.36	11,891	79.44	14,968	1.55
43	21.7	10.76	4.51	78.10	1.35	5.28	13,945	5.71	2.7	34.15	8,386	63.15	13,279	4.77
							ARKANSAS.							
48	14.8	2.33	4.16	89.34	1.60	2.57	15,496	2.36	1.1	12.08	13,259	86.82	15,272	1.45
49	16.7	3.16	4.21	89.28	1.66	1.69	15,624	2.77	2.2	9.07	13,774	88.73	15,525	0.86
49	52.1	0.96	5.11	71.43	1.33	21.17	12,497	39.43	25.1	9.71	6,356	65.19	9,750	22.00
50	21.0	1.43	4.76	85.61	1.76	6.44	14,945	5.26	4.2	24.81	10,451	70.99	14,722	1.77
51	17.0	3.57	3.87	89.57	1.74	1.25	15,530	3.21	2.4	9.29	13,588	88.31	15,387	0.92
51	20.7	1.47	4.50	88.05	1.71	4.27	15,602	3.24	2.1	12.61	13,129	85.29	15,393	1.34
							CALIFORNIA.							
53	53.5	4.62	5.86	71.73	1.00	16.79	12,890	18.51	10.4	15.49	8,507	74.11	11,478	10.95
53	53.8	4.80	6.35	76.03	1.35	11.47	14,336	6.95	2.2	6.23	12,447	91.57	13,593	5.19

TABLE I—*Continued.*

ANALYSES AND HEATING VALUES.

Page of Bulletin 22.	Volatile Matter, % of Combustible	Composition of the Combustible.					B.T.U. per lb. Combustible	As Received.				Air Dry, Ash Free.		
		S	H	C	N	O		M Moist.	L Loss on Air Drying.	A Ash.	B.T.U.	$F=100-(A+L)$.	$\frac{\text{B.T.U.}}{F}=$ B.T.U.	$\frac{M-L}{F}=M_1$
							COLORADO.							
54	41.4	0.44	5.17	76.05	1.37	16.97	11,619	19.65	13.0	6.00	8,638	81.00	10,664	8.21
55	45.5	0.51	5.07	76.22	1.68	16.52	13,239	19.28	5.5	4.70	9,064	89.80	10,094	15.35
55	41.1	0.39	5.18	74.97	1.46	18.00	12,746	17.32	9.9	4.64	9,947	85.46	11,638	8.68
55	31.3	0.72	5.17	83.35	1.38	9.38	14,681	2.64	1.7	5.21	13,529	93.09	14,533	1.01
63	3.6	0.87	3.25	93.34	1.22	1.32	15,413	2.70	1.7	5.83	14,099	92.47	15,247	1.08
70	33.7	0.56	5.62	83.83	1.22	8.77	15,559	2.28	1.5	9.16	13,781	89.34	15,423	0.87
75	23.8	0.58	5.02	88.05	2.01	4.34	15,849	0.96	0.2	8.62	14,330	91.18	15,716	0.83
76	25.8	0.72	5.27	89.80	1.92	2.29	15,939	3.07	1.8	9.16	13,990	89.04	15,712	1.43
							GEORGIA.							
82	19.4	1.55	4.77	86.39	1.33	5.96	15,653	3.80	3.2	14.49	12,791	82.31	15,540	0.74
							IDAHO.							
82	50.9	4.77	....	.....	....	.....	16,457	34.28	24.0	13.38	8,613	62.61	13,757	16.42
							ILLINOIS.							
83	46.0	6.33	5.51	76.23	1.40	10.53	14,263	11.35	5.9	13.40	10,733	80.70	13,300	6.75
83	41.4	1.36	5.22	79.80	1.60	12.02	14,492	8.12	3.6	8.63	12,064	87.77	13,745	5.15
84	37.4	1.14	5.14	83.51	1.75	8.46	14,621	10.72	5.6	9.36	11,686	85.04	13,742	6.02
89	40.8	5.55	5.38	75.51	1.54	12.02	13,921	14.43	9.8	13.28	10,064	76.92	13,084	6.02
89	46.2	6.02	5.44	77.08	1.37	10.09	14,155	13.20	4.4	12.53	10,514	83.07	12,657	10.59
90	40.0	2.82	5.30	80.42	1.72	9.74	14,818	7.81	5.8	8.38	12,418	85.82	14,470	2.34
92	39.3	3.10	5.36	80.89	1.62	9.03	14,724	8.86	5.8	11.66	11,702	82.54	14,177	3.71

							INDIANA.							
93	40.9	2.88	5.48	80.60	1.54	9.50	14,492	16.91	13.1	17.37	9,524	69.53	13,698	5.48
95	42.2	1.78	5.37	80.89	1.41	10.55	14,746	12.11	3.5	6.83	11,952	89.67	13,329	9.60
97	47.3	6.60	5.57	76.68	1.19	9.96	14,305	7.88	3.7	14.20	11,146	82.10	13,576	5.01
99	44.8	6.73	5.48	76.58	1.52	9.69	14,089	13.18	8.5	15.63	10,030	75.87	13,220	6.17
							IOWA.							
99	47.5	5.69	5.35	78.03	1.20	9.73	14,305	14.08	4.5	10.96	10,723	84.54	12,684	11.33
100	51.2	8.53	5.52	75.83	1.16	8.96	14,206	13.88	9.8	14.01	10,244	76.19	13,445	5.35
100	40.6	6.64	5.13	78.96	1.24	8.03	14,555	8.24	3.2	16.00	11,027	80.80	13,647	6.24
							KANSAS.							
101	44.2	9.94	5.54	77.59	1.29	5.64	14,724	6.95	3.5	12.19	11,905	84.31	14,121	4.09
101	39.8	6.68	5.44	81.21	1.41	5.26	15,167	2.50	....	12.45	12,900	87.55	14,734	2.86
101	39.8	5.22	5.40	82.08	1.32	5.98	14,922	4.99	1.3	12.97	12,242	85.73	14,269	4.30
102	39.5	4.93	5.33	81.06	1.41	7.27	14,809	9.04	7.1	15.72	11,142	77.18	14,436	2.49
							KENTUCKY.							
104	44.0	4.29	5.50	79.60	1.71	8.90	14,657	7.92	2.2	10.06	12,022	87.74	13,702	6.52
105	55.5	1.38	7.13	82.59	1.33	7.57	15,800	2.36	1.5	10.49	13,770	88.01	15,646	0.92
105	57.0	1.15	7.46	82.31	1.47	7.61	16,013	1.70	0.4	9.31	14,251	90.29	15,784	1.44
107	35.3	0.58	5.32	84.75	1.30	8.05	15,328	3.41	2.0	5.73	13,928	92.27	15,095	1.64
107	43.5	5.64	5.10	80.26	1.54	7.46	14,836	5.27	2.8	14.18	11,950	83.02	14,394	2.98
							MARYLAND.							
108	16.5	1.13	4.67	89.48	1.91	2.81	15,710	2.70	1.9	8.80	13,910	89.30	15,577	0.90
110	16.0	1.02	4.62	89.85	1.97	2.54	15,640	3.20	2.2	6.70	14,100	91.10	15,478	1.10
110	19.7	0.94	4.85	89.58	1.62	3.01	15,826	3.42	2.7	7.09	14,162	90.21	15,699	0.80
111	17.5	0.98	4.76	89.79	2.00	2.47	15,850	2.60	2.0	6.80	14,360	91.20	15,746	0.66
							MICHIGAN.							
113	38.8	1.53	5.56	81.91	1.46	9.54	14,499	11.91	7.9	6.84	11,781	85.26	13,818	4.70
113	37.1	1.11	5.40	81.52	1.46	10.51	14,603	11.55	6.5	3.25	12,442	90.25	13,786	5.59

TABLE I—*Continued.*

ANALYSES AND HEATING VALUES.

Page of Bulletin 22.	Volatile Matter, % of Combustible	Composition of the Combustible.					B.T.U. per lb. Combustible	As Received.				Air Dry, Ash Free.		
		S	H	C	N	O		M Moist.	L Loss on Air Drying.	A Ash.	B.T.U.	$F=100-(A+L)$.	$\frac{\text{B.T.U.}}{F}=\text{B.T.U.}$	$\frac{M-L}{F}=M_1$
							Missouri.							
114	44.8	5.16	5.51	78.50	1.30	9.53	14,351	14.59	11.1	13.91	10,260	74.99	13.682	4.65
114	47.3	4.85	5.67	77.51	1.29	10.68	14,202	15.36	9.5	10.99	10,460	79.51	15,156	7.37
115	44.6	4.96	5.26	76.55	1.40	11.83	13,892	17.30	15.2	23.38	8,240	61.42	13,416	3.42
116	50.8	6.33	5.61	79.08	1.25	7.73	14,679	10.36	7.4	12.33	11,347	80.27	14,136	3.69
120	45.3	9.45	5.51	77.49	1.27	6.28	14,476	11.40	8.5	15.78	10,541	75.72	13,921	2.83
122	50.2	6.21	5.78	81.05	0.84	6.12	15 134	12.67	7.7	4.83	12,487	87.47	14,276	5.68
							Montana.							
124	33.3	12.99	4.77	74.61	0.81	6.82	13,693	3.04	1.6	37.77	8,105	60.63	13,368	2.37
125	44.4	1.72	5.11	71.06	1.67	20.44	13,338	10.05	2.0	6.02	11,194	91.98	12,170	8.75
125	43.7	2.00	5.41	74.92	1.80	15.87	13,162	9.67	4.1	8.02	10,832	87.88	12,324	6.34
125	37.5	0.86	5.43	76.13	1.37	16.21	13,865	9.76	3.7	16.42	10,235	79.88	12,813	7.58
126	34.3	4.86	4.86	79.90	0.88	9.50	14,134	3.51	1.6	19.50	10,881	78.90	13,791	2.42
127	32.6	2.88	4.03	76.11	0.84	16.14	12,438	10.88	5.4	26.88	7,742	67.72	11,432	8.09
129	69.0	1.86	3.78	69.52	1.37	23.47	11,900	30.00	19.3	11.90	6,914	68.80	10,049	15.55
133	39.6	0.60	5.67	82.75	1.21	9.77	14,681	5.77	3.8	10.57	12,281	85.63	14,342	2.30
133	18.3	0.96	4.29	90.39	1.43	2.93	15,721	2.05	1.5	8.31	14,092	90.19	15,625	0.61
135	54.1	0.67	3.45	68.11	1.13	26.64	10,211	24.59	4.3	14.61	6,208	81.09	7,656	25.02
							New Mexico.							
137	41.5	0.74	5.75	82.89	1.83	8.79	14,875	2.78	1.4	14.57	12,294	84.03	14,630	1.64
138	34.4	0.96	5.67	85.32	1.12	6.93	15,221	2.45	1.8	17.40	12,200	80.80	15,099	0.80
139	44.3	0.68	5.53	79.54	1.55	12.70	14,539	5.02	2.4	12.00	12,064	85.60	14,093	3.06
140	42.8	0.78	5.51	78.43	1.28	14.00	13,939	12.29	1.6	6.99	11,252	91.41	12,309	11.70
141	46.8	2.38	5.59	74.48	1.86	15.69	13,322	15.79	7.6	9.37	9,970	83.03	12,008	9.87

							North Dakota.						
142	49.8	1.16	....	.....	....	.....	11,398	43.78	35.3	3.82	5,972	60.88	9,801	13.93
143	56.7	2.04	4.51	73.61	2.15	17.69	12,557	35.96	12.7	7.75	7,069	79.55	8,886	26.20
144	45.9	0.86	4.61	70.64	1.22	22.67	12,101	38.92	31.7	5.39	6,739	61.91	10,885	11.66
							Ohio.						
145	45.5	4.58	5.47	80.46	1.39	8.10	14,888	4.14	2.6	9.38	12,874	88.02	14,626	1.75
146	37.8	0.63	5.38	80.96	1.45	11.58	14,269	9.72	5.5	4.43	12,247	90.07	14,152	4.69
146	47.7	5.74	5.66	77.78	1.38	9.44	14,332	7.71	4.9	11.95	11,515	85.15	13,523	3.30
147	42.9	3.97	5.45	82.04	1.50	7.04	14,965	3.53	1.4	9.12	13,072	89.48	14,642	2.38
148	42.8	3.66	4.95	81.01	1.37	9.01	14,832	5.59	3.2	8.29	12,773	88.51	14,431	3.83
							Oklahoma.						
148	45.9	5.93	5.18	76.48	1.79	10.62	13,667	8.29	2.7	25.05	9,110	72.25	12,609	7.74
149	21.7	1.15	4.85	89.40	1.75	2.85	15,586	2.37	1.9	8.83	13,840	89.27	15,504	0.53
149	15.7	1.36	4.70	90.23	1.84	1.87	15,728	5.11	4.5	8.03	13,662	87.47	15,619	0.70
150	41.7	2.31	5.50	81.43	1.50	9.26	14,711	7.04	3.3	10.01	12,202	86.69	14,075	4.31
150	35.5	7.36	5.43	81.79	1.71	3.71	15,025	2.09	1.0	20.07	11,695	78.93	14,814	1.38
151	40.8	2.06	5.44	83.06	2.09	7.35	15,061	2.81	1.4	8.75	13,320	89.85	14,825	1.57
							Oregon.						
152	44.0	1.15	5.29	72.20	1.68	19.68	12,769	16.10	8.1	13.17	9,031	78.73	11,471	10.16
152	40.7	5.52	....	.....	....	.....	11,493	13.77	7.8	7.46	9,054	84.74	10,684	7.05
152	48.1	1.65	....	.....	....	.....	14,618	20.84	11.3	8.37	10,348	80.33	12,882	11.88
							Pennsylvania.						
153	38.3	1.38	5.39	84.57	1.72	6.94	15,345	2.61	1.3	6.17	13,997	92.53	15,127	1.42
155	19.0	1.87	4.81	88.71	1.29	3.32	15,840	2.90	2.0	6.74	14,310	91.26	15,680	0.99
157	24.8	1.81	4.84	86.39	1.46	5.50	15,376	4.25	8.9	7.87	13,513	88.23	15,316	0.40
166	25.0	1.50	5.19	88.14	1.45	3.72	15,660	1.90	1.1	6.20	14,390	92.70	15,523	0.86
168	32.4	1.00	5.04	84.87	1.74	7.35	15,511	5.13	4.2	8.71	13,365	87.09	13,346	1.07
169	19.5	1.73	4.93	89.85	1.50	1.99	15,683	1.65	1.3	8.61	14,076	90.09	15,624	1.50
172	1.3	1.00	1.77	94.39	0.71	2.13	14,882	2.80	1.5	7.83	13,298	90.67	14,666	1.43
172	3.7	0.68	3.09	92.91	0.91	2.41	15,248	3.33	2.6	9.12	13,351	88.28	15,123	0.83
175	17.3	1.63	4.46	89.60	1.49	2.82	15,847	1.10	0.5	7.41	14,499	92.09	15,744	0.65
180	17.2	5.09	4.48	87.18	1.59	1.66	15,493	1.78	1.1	9.78	13,702	89.12	15,378	0.76
180	10.0	0.74	3.76	92.15	1.18	2.17	15,457	3.38	2.6	11.50	13,156	85.90	15,315	0.91

TABLE I—*Continued.*

ANALYSES AND HEATING VALUES.

Page of Bulletin 22.	Volatile Matter, % of Combustible	Composition of the Combustible.					B.T.U. per lb. Combustible	As Received.				Air Dry, Ash Free.		
		S	H	C	N	O		M Moist.	L Loss on Air Drying.	A Ash.	B.T.U.	$F=100-(A+L)$.	$\frac{\text{B.T.U.}}{F}=$B.T.U.	$\frac{M-L}{F}=M_1$
							RHODE ISLAND.							
184	6.6	0.05	1.14	93.00	0.22	5.59	13,120	23.68	23.1	30.77	5,976	46.13	12,955	1.26
185	6.3	0.09	0.80	95.62	0.22	3.27	14,002	2.41	2.0	19.06	10,996	78.94	13,930	0.52
							SOUTH DAKOTA.							
185	40.0	0.68	....	.....	....	.....	12,098	30.45	19.7	12.15	6,944	68.15	10,189	15.77
							TENNESSEE.							
186	38.4	1.17	5.59	83.44	1.86	7.94	14,960	6.39	4.7	9.53	12,578	85.77	14,665	1.97
187	33.8	0.95	5.40	85.75	1.20	6.70	15,320	3.89	2.9	14.43	12,514	82.67	15,137	1.08
189	39.8	5.73	5.23	82.41	1.49	5.14	15,125	3.12	2.0	14.12	12,517	83.88	14,921	1.32
							TEXAS.							
189	59.6	1.46	5.67	72.55	1.33	18.99	13,043	34.70	24.6	11.20	7,056	64.20	10,991	15.73
189	70.9	1.00	....	.....	....	.....	12,811	33.50	16.3	10.75	7,142	72.95	9,790	23.58
189	45.3	1.61	5.04	73.21	1.48	18.66	12,890	31.06	23.5	7.88	7,870	68.62	11,469	11.02
190	49.6	0.90	5.17	72.06	1.33	20.54	12,452	33.71	25.8	7.28	7,348	66.92	10,980	11.82
							UTAH.							
191	45.6	0.60	5.44	79.41	1.25	13.30	14,245	5.58	1.1	8.99	12,170	89.91	13,536	4.98
191	47.2	0.62	5.71	81.19	1.55	10.93	14,764	6.05	3.8	4.87	13,151	91.33	14,399	2.47
192	38.4	0.56	4.66	75.14	1.51	18.13	13,118	9.01	4.1	8.18	10,863	87.72	12,384	5.60
193	45.4	7.27	4.97	76.52	1.19	10.05	13,586	10.35	1.8	9.62	10,874	88.58	12,276	9.65
193	44.0	7.10	4.77	72.83	1.12	14.18	13,081	14.19	2.8	9.92	9,927	87.28	11,374	11.47
94	67.6	2.32	7.73	74.75	1.52	13.68	14,918	7.35	1.1	23.24	10,355	75.66	13,686	8.26
194	46.6	4.88	5.08	66.68	1.22	22.14	11,264	16.59	3.9	13.44	7,882	82.66	9,535	15.35

VIRGINIA.													
196	38.3	1.32	5.34	83.97	1.36	8.01	15,156	4.06	2.4	4.73	13,826	92.87	14,887	1.79
197	40.2	0.85	5.25	80.32	1.40	12.18	14,918	4.44	2.1	5.98	13,363	92.92	14,381	2.52
197	13.1	0.82	4.38	89.76	0.86	4.18	15,500	4.80	4.1	18.03	11,961	77.87	15,360	0.90
199	19.0	0.68	4.70	90.08	1.12	3.42	15,840	4.00	3.5	4.31	14,520	92.19	15,750	0.54
200	17.5	0.68	4.86	90.93	1.30	2.23	15,910	4.10	3.5	3.18	14,740	93.32	15,795	0.64
201	35.3	0.97	5.58	86.10	1.70	5.65	15,291	3.31	1.9	3.76	14,209	94.34	15,069	1.49
WASHINGTON.														
202	41.8	0.57	5.66	79.85	1.54	12.38	14,348	6.02	3.5	19.35	10,708	77.15	13,879	3.26
203	47.5	0.44	5.68	75.00	1.77	17.11	13,423	12.05	6.6	10.41	10,414	82.99	12,548	6.56
210	44.0	0.72	5.23	79.40	0.72	13.93	14,796	2.32	1.0	13.58	12,443	85.42	14,569	1.55
214	54.6	0.53	5.25	70.87	1.29	22.06	12,226	27.17	14.3	10.92	7,569	74.78	10,122	17.21
216	8.5	0.72	3.67	91.41	1.53	2.67	15,410	2.70	2.0	10.67	13,350	87.33	15,287	0.80
220	16.3	0.48	4.48	88.91	2.16	3.97	15,264	5.81	4.5	17.04	11,776	78.46	15,013	1.67
WEST VIRGINIA.														
223	47.4	0.92	7.13	85.01	1.60	5.34	16,176	1.80	1.0	3.44	15,330	95.56	16,042	0.84
233	25.3	0.86	5.09	88.33	1.59	4.13	15,399	3.71	2.6	3.39	14,306	94.01	15,218	1.18
235	23.3	0.61	5.19	91.06	1.46	1.68	15,736	5.70	4.9	6.51	13,817	88.59	15,597	0.90
241	21.8	1.27	4.56	87.54	1.11	5.52	15,781	3.94	3.2	4.93	14,382	91.87	15,655	0.81
246	44.3	3.86	5.44	82.13	1.51	7.06	15,291	1.95	0.5	7.86	13,790	91.64	15,048	1.58
247	40.0	0.72	5.30	82.30	1.58	10.10	15,107	4.21	2.3	7.22	13,379	90.48	14,787	2.11
275	19.9	0.60	4.76	90.71	1.13	2.80	16,038	1.75	1.1	4.58	15,023	94.32	15,928	0.69
278	16.5	0.79	4.73	88.71	1.21	4.56	15,820	4.40	3.8	4.10	14,470	92.10	15,711	0.65
281	36.4	0.73	5.14	85.84	1.57	6.72	15,448	2.86	1.6	5.83	14,105	92.57	15,237	1.36
292	18.1	0.86	4.79	90.72	1.66	1.97	15,919	4.26	3.6	6.04	14,279	90.36	15,802	0.73
WYOMING.														
297	27.8	1.09	1.98	85.02	0.97	10.94	12,956	10.26	1.7	9.83	10,354	89.47	11,573	9.56
302	44.3	0.36	4.46	69.17	1.66	24.35	11,722	18.41	10.0	3.71	9,130	86.29	10,581	9.75
303	39.3	0.17	4.67	72.80	0.41	21.95	12,683	17.24	5.6	1.60	10,294	92.80	11,093	12.54
307	59.9	1.18	3.94	70.19	1.28	23.41	11,194	19.17	5.3	37.12	4,892	57.58	8,496	24.09
309	47.5	4.04	4.85	72.51	1.54	17.06	12,447	22.35	7.0	11.54	8,230	81.46	10,103	18.84
311	43.5	0.72	4.00	68.32	1.42	25.54	11,030	23.30	17.3	3.27	8,100	79.43	10,198	7.55
316	50.6	2.17	3.32	63.30	1.35	29.86	9,630	31.37	14.2	10.12	5,634	75.68	7,458	22.69
317	39.3	0.99	5.09	81.14	1.38	11.40	14,848	5.49	3.5	3.12	13,570	93.38	14,532	2.13
318	39.6	0.84	5.18	83.29	1.44	9.25	14,792	3.96	1.4	4.77	13,502	93.83	14,391	2.73
320	49.4	0.77	3.67	61.35	1.07	33.14	10,141	32.18	21.3	5.41	6,329	73.29	8,636	14.85

TABLE II.

CLASSIFIED LIST OF COALS

	Combustible.				Air-dry, Ash-free.	
	Vol.	S.	O.	B.T.U.	Moist.	B.T.U.
I. ANTHRACITE						
Alaska............4........	8.8	0.73	4.04	15,203	1.55	14,968
Colo.............5........	3.6	0.87	1.32	15,413	1.08	15,247
Pa...............7........	1.3	1.00	2.13	14,882	1.43	14,666
Pa...............8........	3.7	0.68	2.41	15,248	0.83	15,123
Wash.............5........	8.5	0.72	2.67	15,410	0.80	15,367
II. SEMI-ANTHRACITE						
Ark..............1........	14.8	2.33	2.57	15,496	1.45	15,272
Pa...............11........	10.0	0.74	2.17	15,457	0.91	15,398
Va...............3........	13.1	0.82	4.18	15,500	0.90	15,439
III. SEMI-BITUMINOUS						
Ala..............1........	28.8	0.59	4.45	15,757	1.15	15,577
Ala..............2........	27.9	1.58	3.42	15,620	0.94	15,475
Alaska...........3........	15.5	1.29	3.02	15,651	0.60	15,559
Ark..............2........	16.7	3.16	1.69	15,624	0.86	15,525
Ark..............5........	17.0	3.57	1.25	15,530	0.92	15,387
Ark..............6........	20.7	1.47	4.27	15,602	1.34	15,393
Colo.............7........	23.8	0.58	4.34	15,849	0.83	15,716
Colo.............8........	25.8	0.72	2.29	15,939	1.43	15,712
Ga...............1........	19.4	1.55	5.96	15,653	0.74	15,540
Md...............1........	16.5	1.13	2.81	15,710	0.90	15,577
Md...............2........	16.0	1.02	2.54	15,640	1.10	15,478
Md...............3........	19.7	0.94	3.01	15,826	0.80	15,699
Md...............4........	17.5	0.98	2.47	15,856	0.66	15,746
Mont.............9........	18.3	0.96	2.93	15,721	0.61	15,625
Okla.............2........	21.7	1.15	2.87	15,586	0.53	15,504
Okla.............3........	15.7	1.36	1.87	15,728	0.70	15,619
Pa...............2........	19.0	1.87	3.32	15,840	0.99	15,680
Pa...............3........	24.8	1.81	5.50	15,376	0.40	15,316
Pa...............4........	25.0	1.50	3.72	15,660	0.86	15,523
Pa...............6........	19.5	1.73	1.99	15,683	1.50	15,624
Pa...............9........	17.3	1.63	2.82	15,847	0.65	15,744
Pa...............10........	17.2	5.09	1.66	15,493	0.76	15,378
Va...............4........	19.0	0.68	3.42	15,840	0.54	15,750
Va...............5........	17.5	0.68	2.23	15,910	0.64	15,795
Wash.............6........	16.3	0.48	3.97	15,264	1.67	15,013
W. Va............2........	25.3	0.86	4.13	15,399	1.18	15,218
W. Va............3........	23.3	0.61	1.68	15,736	0.90	15,597
W. Va............4........	21.8	1.27	5.52	15,781	0.81	15,655
W. Va............7........	19.9	0.60	2.80	16,038	0.69	15,998
W. Va............8........	16.5	0.79	4.56	15,820	0.65	15,804
W. Va............10........	18.1	0.86	1.97	15,919	0.73	15,802
IV. CANNEL*						
Ky...............2........	55.5	1.38	7.57	15,800	0.92	15,646
Ky...............3........	57.0	1.15	7.61	16,013	1.44	15,784
W. Va............1........	47.4	0.92	5.34	16,176	0.84	16,042
Utah.............6........	67.6	2.32	13.68	14,918	8.26	13,686
V. BITUMINOUS, HIGH-GRADE						
Ala..............3........	33.4	1.13	6.99	15,590	1.23	15,400
Ala..............4........	35.3	1.07	7.00	15,214	1.77	14,947
Colo.............4........	31.3	0.72	9.38	14,681	1.01	14,533
Colo.............6........	33.7	0.56	8.77	15,559	0.87	15,423
Ill...............6........	40.0	2.82	9.74	14,818	2.34	14,470
Kan..............2........	39.8	6.68	5.26	15,167	2.86	14,734
Kan..............4........	39.5	4.93	7.27	14,809	2.49	14,436
Ky...............4........	35.3	0.58	8.05	15,328	1.64	15,095
N. Mex...........1........	41.5	0.74	8.79	14,875	1.64	14,630
N. Mex...........2........	34.4	0.96	6.93	15,221	0.80	15,099

* H in combustible: Ky. 2, 7.13; Ky. 3, 7. 46; W. Va. 1,7.13; Utah, 6.7.73. The highes H in the other coals is 5.78, Mo. 6. The figures in the first column are the order of the coals of the several States in Table I.

TABLE II—(*Continued*)

	Combustible.				Air-dry, Ash-free.	
	Vol.	S.	O.	B.T.U.	Moist.	B.T.U.
V. Bituminous High-Grade (*Continued*).						
Ohio..........1........	45.5	4.58	8.10	14,888	1.75	14,626
Ohio..........4........	42.9	3.97	7.04	14,965	2.38	14,642
Ohio..........5........	42.8	3.66	9.01	14,832	3.83	14,431
Okla..........5........	35.5	7.36	3.71	15,025	1.38	14,814
Okla..........6........	40.8	2.06	7.35	15,061	1.57	14,825
Pa..........1........	38.3	1.38	6.94	15,345	1.42	15,127
Pa..........5........	32.4	1.00	7.35	15,511	1.07	15,346
Tenn..........1........	38.4	1.17	7.94	14,960	1.97	14,665
Tenn..........2........	33.8	0.95	6.70	15,320	1.08	15,137
Tenn..........3........	39.8	5.73	5.14	15,125	1.32	14,921
Va..........1........	38.3	1.32	8.01	15,156	1.79	14,887
Va..........2........	40.2	0.85	12.18	14,918	2.52	14,381
Va..........6........	35.3	0.97	5.65	15,291	1.49	15,069
Wash..........3........	44.0	5.23	13.93	14,796	1.55	14,569
W. Va..........5........	44.3	3.86	7.06	15,291	1.58	15,048
W. Va..........6........	40.0	0.72	10.10	15,107	2.11	14,787
W. Va..........9........	36.4	0.73	5.14	15,448	1.36	15,237
Wyo..........8........	39.3	0.99	11.40	14,848	2.13	14,552
VI. Bituminous Medium Grade						
Ala..........5........	37.7	1.37	10.45	14,467	2.69	14,078
Alaska..........1........	44.2	1.83	14.11	13,838	2.55	13,484
Cal..........2........	53.8	4.80	11.47	14,336	5.19	13,593
Ill..........2........	41.4	1.36	12.02	14,492	5.15	13,745
Ill..........3........	37.4	1.14	8.46	14,621	6.02	13,742
Ill..........7........	39.3	3.10	9.03	14,724	3.71	14,177
Ind..........1........	40.9	2.88	9.50	14,492	5.48	13,698
Ind..........3........	47.3	6.60	9.96	14,305	5.01	13,576
Ia..........2........	51.2	8.53	8.96	14,206	5.35	13,445
Ia..........3........	40.6	6.64	8.03	14,555	6.24	13,647
Kan..........1........	44.2	9.94	5.64	14,724	4.09	14,121
Kan..........3........	39.8	5.22	5.98	14,922	4.30	14,269
Ky..........1........	44.0	4.29	8.90	14,657	6.52	13,702
Ky..........5........	43.5	5.64	7.46	14,836	2.98	14,394
Mich..........1........	38.8	1.53	9.54	14,499	4.70	13,818
Mich..........2........	37.1	1.11	10.51	14,603	5.59	13,786
Mo..........1........	44.8	5.16	9.53	14,351	4.65	13,682
Mo..........3........	44.6	4.96	11.83	13,892	3.42	13,416
Mo..........4........	50.8	6.33	7.73	14,679	3.69	14,136
Mo..........5........	45.3	9.45	6.28	14,476	2.83	13,921
Mo..........6........	50.2	6.21	6.12	15,134	5.68	14,276
Mont..........5........	34.3	4.86	9.50	14,134	2.42	13,791
Mont..........8........	39.6	0.60	9.77	14,681	2.30	14,342
N. Mex..........3........	44.3	0.68	12.70	14,539	3.06	14,093
Ohio..........2........	37.8	0.63	11.58	14,269	4.69	14,152
Ohio..........3........	47.7	5.74	9.44	14,332	3.30	13,523
Okla..........4........	41.7	2.31	9.26	14,711	4.31	14,075
Utah..........1........	45.6	0.60	13.30	14,245	4.98	13,536
Utah..........2........	47.2	0.62	10.93	14,764	2.47	14,399
Wash..........1........	41.8	0.57	12.38	14,348	3.26	13,879
Wyo..........9........	39.6	0.84	9.25	14,793	2.73	14,391
VII. Bituminous Low Grade						
Alaska..........2........	40.8	0.94	18.83	12,964	5.42	12,261
Ill..........1........	46.0	6.33	10.53	14,263	6.75	13,300
Ill..........4........	40.8	5.55	12.02	13,921	6.02	13,084
Ill..........5........	46.2	6.02	10.09	14,155	10.59	12,657
Ind..........2........	42.2	1.78	10.55	14,746	9.60	13,329
Ind..........4........	44.8	6.73	9.69	14,089	6.17	13,220
Ia..........1........	47.5	5.69	9.73	14,305	11.33	12,684
Mo..........2........	47.3	4.85	10.68	14,202	7.37	13,156
Mont..........1........	33.3	12.99	6.82	13,693	2.37	13,368
Mont..........2........	44.4	1.72	20.44	13,338	8.75	12,170*
Mont..........3........	43.7	2.00	15.87	13,162	6.34	12,324*

* Montana 2 and 3 are classed as sub-bituminous by the Bureau of Mines.

TABLE II—(*Continued*)

	Combustible.				Air-dry, Ash-free.	
	Vol.	S.	O.	B.T.U.	Moist.	B.T.U.
VII. BITUMINOUS LOW GRADE (*Continued*)						
Mont. 4	37.5	0.86	16.21	13,865	7.58	12,813
Mont. 6	32.6	2.88	16.14	12,438	8.09	11,432
N. Mex. 4	42.8	0.78	14.00	13,939	11.70	12,309*
N. Mex. 5	46.8	2.38	15.69	13,322	7.87	12,008*
Okla. 1	45.9	5.93	10.62	13,667	7.74	12,609
Ore. 3	48.1	1.65	. . . .	14,618	11.88	12,882
Utah. 3	38.4	0.56	18.13	13,118	5.60	12,384
Utah. 4	45.4	7.27	10.05	13,586	9.65	12,276
Utah. 5	44.0	7.10	14.18	13,081	11.47	11,374
Wash. 2	47.5	0.44	17.11	13,423	6.56	12,548
VIII. SUB-BITUMINOUS AND LIGNITE						
Ark. 3	52.1	0.96	21.17	12,497	22.00	9,750
Cal. 1	53.5	4.62	16.79	12,890	10.95	11,478
Colo. 1	41.4	0.44	16.97	11,619	8.21	10,664
Colo. 2	45.5	0.51	16.52	13,239	15.35	10,094
Colo. 3	41.1	0.39	18.00	12,746	8.68	11,638
Mont. 7	69.0	1.86	23.47	11,900	15.55	10,143
Mont. 10	54.1	0.67	26.64	10,211	25.02	7,656
N. Dak. 1	49.8	1.16	. . . .	11,398	13.93	9,801
N. Dak. 2	56.7	2.04	17.69	12,557	26.20	8,886
N. Dak. 3	45.9	0.86	22.67	12,101	11.66	10,885
Ore. 1	44.0	1.15	19.68	12,769	10.16	11,471
Ore. 2	47.0	5.52	. . . .	11,493	7.05	10,684
S. Dak. 1	40.0	0.68	. . . .	12,098	15.77	10,189
Tex. 1	59.6	1.46	18.99	13,043	15.73	11,077
Tex. 2	70.9	1.00	. . . .	10,811	23.58	10,169
Tex. 3	45.3	1.61	18.66	12,890	11.02	11,578
Tex. 4	49.6	0.90	20.54	12,452	11.82	11,036
Utah. 7	46.6	4.88	22.14	11,264	15.35	9,535
Wash. 4	54.6	0.53	22.06	12,226	17.21	10,122
Wyo. 1	27.8	1.09	10.94	12,956	9.56	11,573
Wyo. 2	44.3	0.36	24.35	11,722	9.75	10,581
Wyo. 3	39.3	0.17	21.95	12,683	12.54	11,093
Wyo. 4	59.9	1.18	23.41	11,194	24.09	8,496
Wyo. 5	47.5	4.04	17.06	12,447	18.84	10,103
Wyo. 6	43.5	0.72	25.54	11,030	7.55	10,198
Wyo. 7	50.6	2.17	29.86	9,630	22.69	7,458
Wyo. 10	49.4	0.77	33.14	10,141	14.85	8,666
NOT CLASSIFIED						
R. I. 1	6.6	0.05	5.59	13,120	1.26	12,955
R. I. 2	6.3	0.09	3.27	14,002	0.52	13,930
Alaska. 5	21.7	10.76	5.28	13,945	4.77	13,279
Ark. 4	21.0	1.43	6.44	14,945	1.77	14,722
Idaho. 1	50.9	4.77	. . . .	16,457	16.42	13,757

* New Mexico 4 and 5 are classed as sub-bituminous by the Bureau of Mines.

Wyoming 6, Sample taken 10 ft. from entrance, coal very much weathered; Wyoming 7. Surface exposure; Wyoming 10, Shallow prospect pit; coal badly weathered.

The Rhode Island coals are graphitic and are not used as fuel. Alaska 5 and Arkansas 4 may be classed as semi-bituminous by their percentage of volatile matter, but they are higher in oxygen and in moisture, and lower in heating value than other semi-bituminous coals. The Idaho coal is apparently a cannel coal very high in moisture, but the ultimate analysis is lacking.

Differences between Actual and Calculated Heating Values.—The following table shows the range of variation of heating value as determined by calorimeter from that found by estimation from the Dulong formula, the Mahler curve and the moisture formula.

RANGE OF VARIATION OF HEATING VALUES.

Class.	B.T.U. greater (+) or less (−) than estimated by		
	Dulong Formula.	Mahler Curve.	Moisture Formula
I. Anthracite...........	− 164 to + 127	− 76 to +373	− 385 to + 87
II. Semi-anthracite.......	− 21 to − 193	− 23 to −176	− 233 to −274
III. Semi-bituminous......	− 674 to + 546	− 516 to +208	− 557 to +643
IV. Cannel..............	− 284 to + 172	....	+ 198 to +685
V. Bituminous, high grade	− 344 to + 842	− 849 to +725	− 447 to +908
VI. Bituminous, medium g.	− 673 to + 592	−1226 to +736	− 923 to +967
VII. Bituminous, low grade.	− 309 to +1293	....	−1674 to +689
VIII. Sub-bituminous and lignite............	−1397 to +1292	....	....

For the first five classes the maximum variation of the calorimetric from the estimated value by the Dulong formula is 842 B.T.U., by the Mahler curve 849, and by the moisture formula 908. The revised classification is as follows:

CLASSIFICATION OF COALS.

	Volatile Matter Per Cent of Combustible.	Oxygen in Combustible Per Cent.	Moisture in Air Dry Coal Free from Ash. Per Cent.	B.T.U. per lb. Combustible.	B.T.U. per lb. Coal Air Dry, Ash Free.
I. Anthracite.....	less than 10	1 to 4	less than 1.8	14,800 to 15,400	14,600 to 15,400
II. Semi-anthracite.	10 to 15	1 to 5	less than 1.8	15,400 to 15,500	15,200 to 15,500
III. Semi-bituminous	15 to 30	1 to 6	less than 1.8	15,400 to 16,050	15,300 to 16,000
IV. Cannel *.......	45 to 60	5 to 8	less than 1.8	15,700 to 16,200	15,500 to 16,050
V. Bituminous, high grade........	30 to 45	5 to 14	1 to 4	14,800 to 15,600	14,350 to 14,400
VI. Bituminous, medium grade...	32 to 50	6 to 14	2.5 to 6.5	13,800 to 15,100	11,300 to 14,400
VII. Bituminous, low grade........	32 to 50	7 to 14	5 to 12	12,400 to 14,600	11,300 to 13,400
VIII. Sub-bituminous and lignite...	27 to 60	10 to 33	7 to 26	9,600 to 13,250	7,400 to 11,650

* Eastern Cannel. The Utah cannel is much lower in heating value.

Air-drying of Coal.—In the earlier tests of the Geological Survey the samples were crushed fine, spread out on hollow trays, and dried in the air of the laboratory for 24 to 96 hours, or until the loss between successive weighings (made 12 to 24 hours apart) was small, usually less than 1%. In the later practice the coals after pulverization were dried in a special oven in a gentle current of air of 10° to 20° F. above the temperature of the laboratory. (Bulletin U. S. G. S. 290, 1906, and Professional Paper, U. S. G. S., 48, 1907.) For comparison of results see Bulletin, U. S. G. S., 323, p. 8.

Different Methods of Reporting Coal Analyses.—Much confusion and trouble is experienced by students of coal problems on account of the many different forms in which chemists report the results of forms be adopted when results are published, so as to lessen the their analyses. It is greatly to be desired that one or two standard

trouble of comparing different coals, and, incidentally, to save space and printers' ink. The proximate analysis is given for the coal in one or more of five different conditions, viz., "as received," "air dried," "dried at 105° C," "air-dried free from ash," and "combustible," or "ash and moisture free." Formerly some chemists deducted half of the sulphur from the volatile matter and half from the mixed carbon, calculating the results so that the sum of moisture, ash, volatile matter and fixed carbon, modified as stated together with the sulphur would equal 100 per cent. This practice has fortunately been abandoned, and it is now the custom to report the actual results of the proximate analysis footing up 100 per cent and to give sulphur as separately determined.

The ultimate analysis may also be reported for the coal in any one or more of the five different conditions above named, but in addition it is the custom of some chemists to report the analysis of the coal "as received," "air-dried," or "air-dried ash-free" in such a manner as to make the hydrogen and oxygen include the moisture, while others report the moisture as a separate item, thus making eight different possible forms for the record of the ultimate analysis. The following table shows the several ways in which the analysis of one sample of coal may be reported:

PROXIMATE ANALYSIS.

	As Received.	Air-dried.		Dry Coal.		Air-dry, Ash-free.		Ash- and Moisture-free.	
Moisture........	5	1	1.04	..	......	1	1.15		
Volatile.........	28	28	29.17	28	29.47	28	32.18	28	32.56
Fixed carbon.....	58	58	60.42	58	61.06	58	66.67	58	67.44
Ash.............	9	9	9.37	9	9.47				
	100	96	100.00	95	100.00	87	100.00	86	100.00
Loss on air-drying	4								
Sulphur.........	1		1.04		1.05		1.15		1.16
B.T.U. per lb.....	13,330	13,886		14,032		15,322		15,500	
Form No........	(1)	(2)		(3)		(4)		(5)	

ULTIMATE ANALYSIS.

	As Received.		Air-dry.			Dry Coal.		Air-dried, Ash-free.			Ash-and Moisture-free.	
Moisture.	5	......	1	1.04	......	..	......	1	1.15	......		
Ash......	9	9	9	9.38	9.38	9	9.48					
S........	1	1	1	1.04	1.04	1	1.05	1	1.15	1.15	1	1.16
H........	5	5.56	5	5.21	5.33	5	5.26	5	5.75	5.88	5	5.81
C........	73	73	73	76.04	76.04	73	76.84	73	83.90	83.90	73	84.89
N........	1	1	1	1.04	1.04	1	1.05	1	1.15	1.15	1	1.16
O........	6	10.44	6	6.25	7.17	6	6.32	6	6.90	7.92	6	6.98
	100	100.00	96	100.00	100.00	95	100.00	87	100.00	100.00	86	100.00
Form No.	(6)	(7)		(8)	(9)		(10)		(11)	(12)		(13)

The figures in the columns footing respectively 96, 95, 87 and 86, are here given to show the figures that were used in obtaining the several percentages; they would be omitted in a report.

Here are thirteen different forms for reporting the analysis of a single sample of coal. Which of them are useful? Form (1) is the usual proximate analysis as actually made; form (5) is calculated directly from (1). If the volatile matter in the combustible (form 5) is less than 38 per cent, the heating value per pound of combustible may be approximated (except in the case of some coals of the far West) with an error of not over 2 per cent by means of the figures in the table on page 56, viz.:

Vol. Matter.	B.T.U. per lb.	Vol. Matter.	B.T.U. per lb.	Vol. Matter.	B.T.U. per lb.
3	14,940	13	15,660	32	15,480
6	15,210	20	15,840	37	15,120
10	15,480	28	15,660	40	14,760

Beyond 40 per cent volatile matter the heating value has no direct relation to the volatile matter on account of the great variation in the percentage of oxygen in that volatile matter. Form (5) is, therefore, useful as an indication of the kind of coal and, with the exceptions above mentioned, of its approximate heating value. Form (4) is important, since the percentage of moisture in the air-dried coal is an index to the quality of the real coal substance, that is the coal free of ash and of surface moisture. Forms (2) and (3) are of no use for comparing classes of coal, until their figures are converted into other forms, since they include the ash, an accidental variable.

Of the ultimate analyses, form (9) shows the actual analysis of the air-dried coal, and it may be useful as a record of the original results obtained, but the figures are otherwise of no essential importance until the moisture has been separated from the hydrogen and oxygen, as in form (8), and from ash, as in form (13). This form (13) is the one which gives all the essential figures of the ultimate analysis, and which shows the composition of the combustible.

Omitting all the unessential figures we may construct a new table, which gives all the data that are really needed for either commercial or scientific purposes, as follows:

PROXIMATE ANALYSIS.

Coal as Received.				Air-dry, free from Ash.		Combustible.	
Loss on Air-drying.	Moisture.	Ash.	B.T.U. per lb.	Moisture.	B.T.U.	Vol. Mat.	B.T.U.
4.00	5.00	9.00	13,330	1.04	15,322	32.56	15,500

ULTIMATE ANALYSIS.

Coal Dry and Free from Ash, or Combustible.						B.T.U. actual greater, + or less − than Calculated
S.	H.	C.	N.	O.	B.T.U. Calculated.*	
1.16	5.81	84.89	1.16	6.98	15,427	−73 = 047%

* By Dulong's formula.

If the fixed carbon is desired for any purpose it may be obtained by subtracting the volatile matter, 32.56 from 100, giving 67.44. If it is desired to reproduce the original proximate analysis, footing up to 100 per cent, it may be done by multiplying 32.56 and 67.44 respectively by $100-(5.00+9.00)$ giving 28.0 and 58.0, but these figures are of no value except as original records of the analysis.

For the purpose of tabulating a long list of coals, all the figures above given for both proximate and ultimate analysis may easily be printed in a single line, in 6-point type, running lengthwise of the page. Bulletin No. 22 of the Bureau of Mines contains no less than 289 pages of analyses, averaging about 40 to the page, taking three lines for each coal, viz.: "as received," "dried at 105°," and "moisture and ash-free," and in some cases a fourth line is given, "moisture, ash and sulphur free." Both proximate and ultimate analyses are given for each of the three conditions, and yet the tables do not give several items of important information that are given in the brief table above, viz.: moisture and B.T.U. of the air-dried coal free from ash; B.T.U. per lb. combustible calculated by Dulong's formula; and the difference between that value and the B.T.U. per lb. combustible obtained by the calorimeter. The vast labor of calculating the ultimate analyses for coal as received and as dried at 105° C., could have been saved, two-thirds of the size of the book could have been dispensed with, and the table would have given more information to users of the Bulletin, if the tables had been arranged in the brief form shown above.

Reliability of Dulong's Formula.—Suppose we have a fuel whose composition is

$$C_5H_6O_2$$
$$60 + 6 + 32 = 98 \text{ parts by weight.}$$

If the O was inert or uncombined, the heating value of this fuel would be

$$60 \times 146 + 6 \times 620 = 12{,}480 \text{ B.T.U. for } 0.98 \text{ lb.}$$

According to the supposition of Dulong's formula that all of the O is combined with H, the composition would be represented by

$C_5H_2 + 2H_2O$
$60 + 2 + 36 = 98$. Heating value, $60 \times 146 + 2 \times 620 = 10{,}000$ B.T.U.

It is possible, however, that the O and the H may be combined with C in several different ways; for example:

		Heating Value.	
$C_3H_6 + 2CO$			
$36 + 6 + 56$	$= 98.$	$36 \times 146 + 6 \times 620 + 56 \times 44.5$	$= 11{,}468$ B.T.U.
or			
$C_4H_6CO_2$			
$48 + 6 + 44$	$= 98.$	$48 \times 146 + 6 \times 620$	$= 10{,}728$ "
or			
$C_4H_4 + CO + H_2O$			
$48 + 4 + 28 + 18$	$= 98.$	$48 \times 146 + 4 \times 620 + 28 \times 44.5$	$= 10{,}736$ "
or			
$C_{4.5} + 0.5CH_4 + 2H_2O$			
$54 + 8 + 36$	$= 98.$	$54 \times 146 + 8 \times 236$	$= 9{,}772$ "
or			
$C_3 + CH_4 + CO + H_2O$			
$36 + 16 + 28 + 18$		$36 \times 146 + 16 \times 236 + 28 \times 44.5$	$= 10{,}278$ "

Showing that the heating value may range from 14.7% greater to 2.3% less than that calculated by Dulong's formula.

The table of Mahler's results, page 143, shows that the actual heating value of a cannel coal, No. 26, was 3.28% less than that calculated by Dulong's formula; that of a lignite, No. 33, was 4.75% greater; turf from Bohemia, 14.2% greater; two samples of wood averaged 9.1% greater; and cellulose 16.1% greater than the calculated value.

Let us apply some of the above suppositions to two of these cases, the cannel coal and the cellulose.

The actual heating value of the combustible of the cannel coal is 8431 calories; calculated value 8717; difference 286, or 3.28% of the calculated value. Its composition is C, 83.79; H, 6.57; O + N, 9.64. Taking N = 1, assuming that 1.08 H is combined with 8.64 O as H_2O and that the remaining 5.49 H is combined with 16.47 C as CH_4 we have

$$83.79 - 16.47 = 67.32\ C \times 81.40 = 5480 \text{ calories}$$
$$5.49 + 16.47 = 21.96\ CH_4 \times 131.20 = 2881 \text{ “}$$

Total 8361 calories, which is only 70 calories or 0.83% less than the actual value.

The cellulose, $C_{12}H_{10}O_{10}$ is 44.44 C; 6.17 H; 49.39 O; actual heating value 4200 calories; calculated by Dulong's formula 3617. Difference 58.3 calories, or 14% of the actual value.

Suppose that the

49.39 O is combined with 3/11 of 49.39 or 13.47 C as CO_2

and 6.17 H “ “ “ 3×6.17 or 18.51 C as CH_4,

leaving 12.46 C uncombined; we then have

$$6.17 + 18.51\ C = 24.68\ CH_4 \times 131.20 = 3238$$
$$12.46\ C \times 81.40 = 1014$$

Total 4252 calories, as compared with 4200, the actual value.

Dulong's formula, however, gives results that are remarkably close to the actual with all ordinary coals. It is only with lignite, wood and other fuels high in oxygen, and in some fuels high in hydrogen, such as cannel coal and methane, CH_4, that it fails. The actual heating value of CH_4, according to Thomsen is 13,120 calories, while its value calculated by Dulong's formula is 14,730 calories, the difference, 1610 calories, being 12.27% of the actual value.

Nature of the Volatile Matter in Coal.—H. C. Porter and F. K. Ovitz, of the U. S. Geological Survey, in a paper presented to the American Chemical Society in 1909,* gave the following tables of results obtained by heating samples of coal to different temperatures. They show that the volatile product of coal is to some extent incombustible, that the proportion of inert volatile varies in different coals, and that the oxygen of coal is in many cases evolved in the volatile matter very largely in combination with carbon as CO and CO_2 as well as with hydrogen as water, thereby explaining in great degree the discrepancy found in these cases between the determined calorific value and that calculated by Dulong's formula.

* See also Bulletin No. 1 of the U. S. Bureau of Mines.

TABLE I.

ANALYSIS OF COAL USED IN EXPERIMENTS.

	Moisture.	V. M.	F. C.	Ash.
Connellsville, Pa.	1.10	30.67	60.35	7 88
Ziegler, Ill.	7.67	30.38	54.32	7.63
Sheridan, Wyo.	9.15	39.93	42.92	8.00
Pocahontas, W. Va.	0.35	20.93	75.51	3.21

TABLE II.

AVERAGE RESULTS OF 10 GRAMS AIR-DRIED COAL.

Coal.	Highest Tem. in Coal.	Tar.	Water.	Gas. (ccs)	Gas Composition. (Calculated to undiluted gas.)						
					CO_2.	Illum.	CO.	CH_4	(a) C_2H_6.	H.	N.
10 minutes heating at 500° C.											
Connellsville, Pa.	335	..	....	8	30.0	0	6.5	6.5	7.0	0	50.0 (*b*)
Ziegler, Ill.	325	..	....	90	14.8	0	5.3	8.0	..	0	71.9 (*b*)
10 minutes heating at 600° C.											
Connellsville, Pa.	441	4.9	3.2	190	6.3	8.2	5.9	36.9	23.7	2.0	17.0 (*b*)
Ziegler, Ill.	440	6.8	13.0	173	15.7	7.0	14.4	19.0	22.2	2.8	18.9 (*b*)
10 minutes at 700° C.											
Connellsville, Pa.	562	11.0	3.5	583	3.0	7.2	5.4	44.1	17.7	13.5	9.1
Ziegler, Ill.	545	7.8	14.0	471	8.5	5.1	13.7	59.6	0	1.1	12.0
Sheridan, Wyo.	580	8.2	18.5	1020	28.8	3.7	20.0	18.6	6.8	15.1	7.0
Pocahontas, W. Va.	599	4.2	1.9	675	1.9	4.4	3.9	44.4	16.1	28.5	0.8
10 minutes at 800° C.											
Connellsville, Pa.	687	12.6	4.5	1375	1.5	5.5	6.9	24.9	12.1	33.1	16.0 (*b*)
Ziegler, Ill.	680	9.3	13.9	1251	3.8	3.8	16.0	27.7	6.1	33.7	8.9 (*b*)
Sheridan, Wyo.	....	7.9	19.1	1780	19.8	2.7	21.4	14.1	4.0	30.0	8.0
Pocahontas, W. Va.	....	6.5	2.4	1590	1.2	3.4	4.8	24.4	11.6	43.2	11.4

(*a*) Includes all higher paraffin hydrocarbons calculated as C_2H_6.
(*b*) Includes small amount of air.

TABLE III.

ABSOLUTE QUANTITIES OF SMOKING AND NON-SMOKING PRODUCTS.
(10 Minutes Heating of 10 grams Air-dried Coal.)

Designation of Coal.	Temperature °C.		Smoking Products.				Nonsmoking Gases (cu.cm).				
	Furnace.	Coal.	Tar, Per Cent.	Gas (cu.cm.).			CO_2.	CO.	CH_4.	H.	Total
				Illum.	Ethane, etc.	Total.					
Connellsville, Pa.	500	335	...	0	0.6	0.6	2.4	0.5	0.5	0	3.4
Ziegler, Ill.	500	325	...	0	0	0	13.5	4.7	7.2	0	25.4
Connellsville, Pa.	600	441	4.9	16	46	61	12	11	71	4	98
Ziegler, Ill.	600	440	6.8	12	39	51	28	25	33	5	91
Connellsville, Pa.	700	562	11.0	42	103	145	18	31	256	78	383
Ziegler, Ill.	700	545	7.8	24	0	24	40	64	281	5	391
Sheridan, Wyo.	700	580	8.2	38	69	107	294	204	190	154	842
Pocahontas, W. Va.	700	599	4.2	30	109	138	13	27	300	192	532
Connellsville, Pa.	800	687	12.6	76	166	242	21	95	343	458	917
Ziegler, Ill.	800	680	9.3	47	76	123	47	200	346	420	1013
Sheridan, Wyo.	800	...	7.9	48	72	120	355	381	254	534	1524
Pocahontas, W. Va.	800	...	6.5	54	186	240	19	77	390	691	1177

Relation of Quality of Coal to the Capacity and Economy of a Boiler.—The actual evaporating capacity of a boiler containing a given amount of heating surface and a given area of grate depends primarily upon the quantity of heat which may be generated in the furnace. This depends on the quantity of coal that may be burned, and also on its quality. The better the quality the greater number of heat-units will be generated by the combustion of each pound. If the coal is high in moisture or in oxygen, not only will the heat-units derived from a pound of it be low, but the attainable temperature will also be lower than that attainable from a better coal; and furnace temperature, as will be shown in another chapter, is an important factor of both capacity and economy.

If the coal is high in ash, not only is its value per ton diminished, but the quantity of ash formed on the grate tends to check the air-supply, and therefore to diminish the rate of combustion, and consequently the quantity of steam generated. If the coal is high in sulphur, the ash will be apt to fuse into clinker, and this may choke the grates completely, necessitating frequent cleaning of the fire, involving extra labor, loss of unburned coal removed with the ashes in cleaning, the loss of heat of the furnace by keeping the fire doors open during the time of cleaning.

In order to develop the rated capacity of a boiler with poor coal high in ash, it is necessary to have either a larger grate surface or stronger draft than with good coal. Sometimes strong draft is of no avail, on account of the clinkering of the ash, and in such a case large grate surface is absolutely required.

The quality of coal, therefore, is a most important factor of both the capacity and economy of a boiler. It is possible with a good free-burning coal to obtain from a given boiler twice as much steam as can be obtained with the same boiler and the same draft from poor coal, and the relative economy obtainable with the two coals, or the steam generated per pound of coal, may differ 30 or 40 per cent.

The quality of the coals of the United States varies greatly in different districts. In some limited districts the very best quality is regularly found; in other districts the quality is uniformly from good to medium, and in still others it ranges from poor to worthless.

To buy coal on the reputation of the district in which it is mined is not as good a way as to buy it on a guarantee of quality, as determined by an analysis for water, volatile matter, ash, and sulphur, but it is the most common way. A knowledge of the quality of coals

found in different districts is therefore of some importance. Another chapter, "Coal-fields of the United States," is devoted to this subject.

It is usually found that under the most favorable conditions of firing, moderate rate of driving and proper air supply, the maximum boiler efficiency is obtained only with coal of a high heating value per pound of combustible. This is accounted for by the fact that the coals that have a low heating value per pound of combustible are usually high in volatile matter and in moisture. It is difficult to burn all the volatile matter when its quantity is excessive, and the excessive moisture not only carries away heat in the chimney gases but it also tends to lower the temperature of the fire and thus to reduce efficiency.

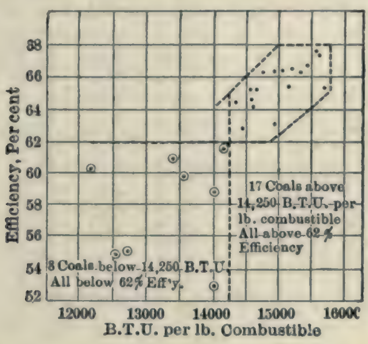

FIG. 4.—RELATION OF HEATING VALUE AND EFFICIENCY.

The tendency of efficiency to vary with the heating value per pound of combustible is well shown by the results of the tests of the U. S. Geological Survey made at St. Louis in 1904,* which are given in the table on page 82.

The relation of the boiler efficiency to the heating value per pound of combustible is plotted in the accompanying chart.

In 14 out of the 23 States coals were obtained having heating values between 14,290 and 15,700 B.T.U. per pound combustible, and which gave boiler efficiencies of from 64 to 67.6 per cent. For 15 out of 17 coals from these States, the results are plotted in the narrow field at the top of the diagram, and they may all be represented by the equation $E = 69 - 2.5\ (16 - H) \pm 1$, in which H is the heating value per pound combustible in thousands of B.T.U. The coals of lower heating value than 14,290 all gave efficiencies below 62 per cent, ranging down to 53.11 per cent for the Rhode Island graphitic coal.

* Bulletin No. 23 of the U. S. Bureau of Mines, 1912.

TABLE SHOWING NUMBER OF COALS TESTED FROM EACH STATE AND AVERAGES OF PRINCIPAL RESULTS.

State.	Kind of Coal.	No. of Coals.	Percentage of Builders Rated Horsepower.	Equivalent Evaporation Coal as Fired at and from 212° F.	Efficiency of Boiler and Grate.	Efficiency of Boiler.	B.T.U. per lb. of Dry Coal.	B.T.U. per lb. of Combustible
Alabama	Bituminous	4	91.9	8.08	64.31	66.42	12,656	15,016
Arkansas	Semi-bit	7	89.3	8.77	63.54	66.81	13,707	15,473
"	Lignite*	1	104.0	3.59	59.26	60.25	9,549	12,180
Colorado	Bituminous	1	71.9	5.78	55.36	61.26	12,577	13,478
Florida	Peat†	1	113.2	5.00	57.85	58.19	10,082	11,003
Illinois	Bituminous	25	89.6	7.05	62.66	64.60	12,249	14,294
Iowa	"	5	90.7	6.24	59.55	61.83	11,650	14,216
Indiana	"	11	89.5	7.33	63.76	65.28	12,549	14,504
Indian Territory	"	4	94.9	7.73	61.69	64.04	12,820	14,561
Kansas	"	6	83.4	7.72	61.26	63.17	12,780	14,949
Kentucky (East)	"	3	91.0	9.33	65.41	66.69	14,417	15,169
" (West)	"	3	88.9	7.70	62.82	64.73	12,883	14,547
Maryland	Semi-bit	1	80.1	8.90	63.96	65.29	13,680	15,681
Missouri	Bituminous	7	92.2	6.73	60.18	62.99	12,246	14,465
New Mexico	Lignitic	2	96.5	6.15	55.45	58.96	12,021	14,009
" "	Bituminous	3	104.2	8.11	64.68	66.50	12,507	14,941
North Dakota	Lignite	1	71.3	3.79	53.29	55.34	10,719	12,511
Ohio	Bituminous	9	92.2	8.32	64.88	66.31	13,130	14,740
Pennsylvania	Semi-bit	9	89.9	9.48	66.22	67.53	14,218	15,595
Rhode Island	Graphitic	1	55.8	4.81	40.91	53.11	11,639	14,001
Tennessee	Bituminous	9	102.3	8.43	64.18	65.55	13,264	15,093
Texas	Lignite	1	86.1	4.19	53.34	55.48	11,102	12,731
Virginia	Bituminous	4	94.2	9.36	65.07	66.28	14,436	15,281
Washington	Lignitic	2	98.7	7.85	63.45	65.25	12,725	14,599
West Virginia	Semi-bit	21	95.5	9.54	65.89	67.64	14,451	15,544
Wyoming	Lignite	5	87.7	5.75	56.85	59.85	11,337	13,572

* Forced draft. † Natural draft, 0.8 inch of water.

Effect of Size of Coal on Boiler Efficiency. (A. Bement, *Jour. Western Soc'y of Engrs.,* Dec. 1906).—The size of the pieces of coal exercise an important influence, not only on the capacity which may be produced by a boiler, but on the resulting efficiency, and the best size to be used in a given case is dependent upon many conditions, such as the strength of draft, kind of stoker or grates, method of firing, etc., and the selection of the proper size of fuel or the method of utilizing the available size, often affords an opportunity to effect important economies.

Valuing Coals by Test and by Analysis.—The best way to obtain the relative value of different coals for any particular steam-boiler plant is to have a car-load of each coal tested under the ordinary running conditions of the plant, and then to check the results by a proximate analysis of each. The coal that is most economical for one boiler-plant is not necessarily the most economical for another, on account of the differences in conditions, such as kind of furnace, area

of grate surface, draft available, etc.* A plant designed for the purpose may be able to use with satisfaction the poorest quality of the fine sizes of anthracite, while another may not be able to use anything cheaper than the best pea coal, and still another, having deficient grate surface, may be compelled to use egg size, or even semi-bituminous.

Besides testing the coals by burning them under the boilers and weighing the quantity of water evaporated, a proximate analysis of each coal should be made so as to arrive at a standard of quality by reference to which future purchases may be made.

Selection of Coal for Steam-boilers.—The selection of the kind of coal to be used in any given boiler-plant depends: (1) on the relative cost per ton of the different kinds delivered at the boiler; (2) on their relative total heating value per pound or per ton; (3) on the relative percentage of the heating value which may be utilized in the boiler; (4) on the maximum capacity, or horsepower, which may be developed by the boilers with different coals; (5) on the relative cost of handling the different coals and the ashes produced from them; and (6) on their relative smokelessness when used in the particular boilers and furnaces under consideration.

In some locations only one kind of coal is practically available, as when the boilers are located near a coal-mine, all other kinds being relatively too high-priced on account of the freight that must be paid on them. In such cases, for the best results, the furnace and the draft must be adapted to the coal at hand. If the coal is of poor quality, the grate surface must be large relatively to the heating surface. If it is anthracite rice or culm, the draft must be strong, and, unless the grate surface is very large, mechanical draft may be necessary. If the coal is bituminous, the area of the grate, in proportion to the heating surface, will depend on the quality; the poorer the quality the larger the grate required. In other locations many different varieties of coal may be available, and then all of the points above enumerated may have to be taken into account in making a selection.

Usually the coal which is sold at the lowest price per ton is the most economical one for those furnaces and boilers that are adapted to it. Its price is apt to be depreciated below the normal price due to its

* An example of this is seen in locomotive practice, in which it is found that semi-bituminous coal of the highest heating value does not give as high economy at high rates of driving as eastern bituminous coal, which is about 5% lower in heating value, on account of the fact that a larger percentage of semi-bituminous coal is blown out of the stack in the shape of sparks and cinders.

heating value, because its market is limited by the number of boilers to which it is adapted, and also by the cost of freighting it to more distant markets. Freight charges being the same per ton on poor as on good coal, it does not pay to haul poor coal long distances; it is better to sell it at a relatively low price in nearby markets. On the other hand, good coals are apt to be relatively overvalued in the market, since they can be used in all kinds of furnaces, are more desirable in every way, and they may be transported long distances to find the best markets. On this account a boiler and furnace should be adapted, whenever possible, to use the poorest kind of coal in the market.

But this is not always possible. The boiler and chimney being already in place and the requirements of the engines being such that the boiler must be driven to its maximum capacity, then a coal must be selected from which this maximum capacity may be obtained.

For maximum evaporation per pound of coal, that coal should be selected in which the product of its total heating value per pound by the percentage of this heating value which may be utilized by the boiler, is a maximum. For instance, suppose an anthracite egg-coal of a heating value of 13,000 heat units per pound and a good bituminous coal of 14,000 heat units are equally available, but the furnace is such that the boiler will give 75 per cent efficiency with the anthracite and only 65 per cent with the bituminous, then the relative values of the two coals for that particular boiler are 975 for the anthracite and 910 for the bituminous. If a semi-bituminous coal with a heating value of 14,500 heat units is also available, and the boiler-efficiency with that coal is 70 per cent, then its relative figure will be 1015. If maximum capacity, rather than economy, is the prime consideration, then the bituminous coal, with the lowest relative economy of the three, may be selected if it is found that it is more free-burning than the others, so that a larger quantity of it may be burned in the furnace with the draft that is available. If economy of cost is the chief consideration, the boiler having ample capacity with either fuel, then that coal will be selected which evaporates the most water for the least money, or in case of the three coals considered, the one in which its price per ton divided by its relative value figure, 975, 910, or 1015, as the case may be, is the least. If their costs per ton are respectively \$1.95, \$1.82, and \$2.03, then the prices of the coals are directly proportioned to their available actual values for the particular case, and as far as cost is concerned it is a matter of indifference which is selected. The selection may then depend on the trifling

difference between the coals in the relative cost of handling them, or in handling the ash made from them, the bituminous coal usually requiring the greater labor on the part of the fireman. If the location is in a city, where smoke is objectionable, the anthracite coal may be selected on account of its smokelessness.

Specifications for Purchase of Coal.—It is customary with very large consumers of coal to issue specifications of quality, upon which sellers are asked to make bids, and on receipt of the coal to have it carefully sampled and tested to ascertain whether it is of the quality prescribed. The following specifications are recommended by the author:

Anthracite and Semi-anthracite.—The standard is a coal containing 5 per cent volatile matter, not over 2 per cent moisture, and not over 10 per cent ash. A premium of 0.5 per cent on the price will be given for each per cent of volatile matter above 5 per cent up to and including 15 per cent, and a reduction of 2 per cent on the price will be made for each 1 per cent of moisture and ash above the standard.

Semi-bituminous and Bituminous.—The standard is a semi-bituminous coal containing not over 20 per cent volatile matter, 2 per cent moisture, 6 per cent ash. A reduction of 1 per cent in the price will be made for each 1 per cent of volatile matter in excess of 25 per cent, and of 2 per cent for each 1 per cent of ash and moisture in excess of the standard.

Western Coals.—For Western coals, in which the volatile matter differs greatly in its percentage of oxygen, the above specification may not be sufficiently accurate, and it is well to introduce the heating value, as determined either by a calorimeter or by a calculation from the ultimate analysis, as below:

The standard is a coal containing not over 6 per cent moisture and 10 per cent ash in an air-dried sample, and whose heating value is 14,500 B.T.U. per pound of combustible. For lower heating value of the combustible the price shall be reduced proportionately, and for each 1 per cent increase in ash or moisture above the specified figures, 2 per cent of the price shall be deducted.

Government Coal Purchases under Specifications. (Bureau of Mines Bulletin No. 41, 1912).—In order to award a contract properly, the proposals should be reduced to a common basis for comparison. The preferable method is to adjust all bids on a given lot of coal to the same ash percentage by selecting as the standard that proposal

which offers the coal containing the lowest percentage of ash. Each 1 per cent of ash above that of this standard is assumed to have a negative value of 2 cents a ton, the amount of the penalty which is exacted under the contract requirements for 1 per cent excess of ash. The proposal prices are all adjusted in this manner and are so tabulated. On the basis of the adjusted price, allowance is then made for the varying heat values by computing the cost of 1,000,000 British thermal units for each coal offered. In this way the three variables—calorific value, percentage of ash, and basic price per ton—are all merged into a single figure, the cost of 1,000,000 British thermal units, by which one bid may be readily compared with another.

An example of this manner of abstracting bids is shown below:

Bidder.	Commercial Designation of Coal.*	Mine and Location.*	Coal Bed.*	Heating Value of Coal "as Received."	Ash in "Dry Coal."	Price per Ton.		Cost per 1,000,000 B.T.U.
						Bid.	Plus Ash Difference.	
				B. t. u.	*Per cent.*			*Cents.*
A	....	....	......	13,400	10.0	$2.35	$2.43	8.096
B	....	....	......	14,000	8.0	3.15	3.19	10.172
C	....	....	......	14,600	6.0	3.25	3.25	9.938
D	....	....	......	13,000	10.0	3.10	3.18	10.920
E	....	....	......	13,000	8.0	2.35	2.39	8.207
F	....	....	......	13,000	10.5	2.35	2.44	8.379
G	....	....	......	11,500	13.5	2.25	2.40	9.317

* These columns are filled in from data given in proposals.

The heating values stipulated by the different bidders being different, the calorific cost is computed for each bid by the formula:

$$\frac{1{,}000{,}000 \times \text{adjusted price per ton}}{2240 \times \text{B. T. U.}} = \text{cost per } 1{,}000{,}000 \text{ B. T. U.}$$

Government contracts in 1909–11 were based either on a standard heating value for coal "as received" and a standard percentage of ash "dry coal" or on an ash "dry coal" standard only. The first basis is applicable to all coals, the second to anthracite only. For 1912-13 the heating value is expressed on the "dry coal" basis. For forms for specifications and proposals see Technical Paper 15, Bureau of Mines, 1912.

Two classes of coal, anthracite and bituminous, are recognized in Government specifications. By bituminous coal is meant varieties other than anthracite, including the several grades of semi-bituminous and sub-bituminous.

As the coal is weighed when delivered, and payments are made according to the price per ton, it is necessary to determine the heating value of the coal in the condition in which it is received with whatever moisture it may then contain. A further correction in payment is made for variation in ash in dry coal in order to take account of the cost of handling additional fuel and ash and of its effect on the capacity of the boiler and furnace.

In purchasing anthracite on the single standard, corrections of the contract price are made as in the following table:

Size.	Standard Ash.	If Ash is Per Cent above (or below) Standard					
		½	1	1½	2	2½	3
		Deduct (or Add) Cents per Ton.					
Furnace and egg....	8.01–12	15	18	21	24		
Stove............	10.01–14	15	18	21	24	27	
Chestnut..........	12.01–16	15	18	21	24	27	
Pea..............	14.51–17	5	7.5	10	12.5	15	
Buckwheat........	17.01–19 a	4	8	14	21	32	48
	17.01–19 b	4	6	8	10	12	

a, cents per ton to be deducted if ash is above standard.
b, " " added if ash is below standard.

In purchasing bituminous coal no deduction is made if the ash is not more than 2 per cent higher than that named in the proposal. For higher percentages deductions are made as below:

Ash above proposal, %	2.01–3	3.01–4	4.01–5	5.01–6	6.01–7
Cents per ton deducted	2	4	7	12	18
If ash proposed is.....	5 to 7	8 to 10	11 to 14	15 to 18%	
Maximum limit is.....	7	6	5	4% higher	

Corrections for variation in heating value above or below the standard established in the contract are determined by the formula

$$\frac{\text{Delivered B.T.U.}}{\text{Standard B.T.U.}} \times \text{contract price} = \text{price to be paid.}$$

U. S. Government Tests, 1909–1910.

ANTHRACITE.

As Received.			Volatile Per Cent of Combustible.	B.T.U. per lb. Combustible.	Location and Size.
Moisture.	Ash.	Sulphur.			
6.06	13.83	0.75	9.0	14,940	Anthracite screenings
4.17	10.86	0.79	7.0	14,890	Phila. & Reading anthracite screenings
5.93	16.80	0.95	8.7	14,700	Pittston, No. 2 buckwheat
5.29	12.96	0.89	6.9	14,890	Anthracite screenings
3.62	17.16	0.82	7.3	14,900	Pittston, pea
6.26	17.20	0.82	8.4	14,850	" No. 2 buckwheat
3.33	13.47	0.64	7.6	14,870	Plymouth, No. 1 pea
4.93	16.90	0.65	6.7	14,810	Lehigh pea
5.45	14.00	0.64	10.5	14,950	Nanticoke, barley
3.67	9.62	0.66	6.1	15,000	" egg
3.34	10.84	0.65	5.5	14,820	Kingston, grate
2.12	15.65	0.58	10.7	15,290	Bernice, egg
3.38	9.31	0.60	5.5	14,990	Moreau & Lehigh, broken
4.55	17.87	0.59	5.9	14,760	Phila. & Reading, No. 1 buckwheat
6.21	17.45	0.56	7.4	14,600	Girard, Mammoth, No. 2 buckwheat
					SEMI-BITUMINOUS.
1.92	7.13	1.39	21.5	15,720	Cambria Co., Pa., run-of-mine
2.16	6.29	1.86	22.5	15,710	" " "
6.06	13.83	0.75	21.5	15,680	" " "
2.59	8.21	2.44	23.9	15,610	" " "
1.98	8.84	2.23	24.0	15,590	" " "
2.19	6.43	1.59	22.4	15,720	" " "
3.05	6.84	1.79	22.0	15,670	" " "
2.26	7.29	1.69	20.9	15,730	" " "
2.60	6.96	1.53	21.0	15,710	" " "
2.80	8.94	0.88	19.0	15,630	Somerset Co., Pa., run-of-mine
2.56	9.39	0.93	18.7	15,610	" " (73,000 tons)
2.89	7.76	1.31	24.5	15,630	Clearfield Co., Pa., run-of-mine
2.63	10.09	....	....	15,810	W. Salisbury, Pa., run-of-mine
3.16	6.12	0.68	20.1	15,720	Pocahontas and New River, W. Va.
2.14	4.73	1.01	23.4	15,650	New River, Fayette Co., W. Va.
3.03	5.24	0.66	22.2	15,790	Pocahontas, Va., Big Vein
2.63	5.25	0.64	19.8	15,770	Pocahontas, run-of-mine (407,000 tons)
2.36	7.38	0.81	20.6	15,660	" Thin Bed, near Welch, Va.
3.08	4.57	0.66	19.0	15,770	" Mercer and McDowell Cos., W. Va.
2.22	4.92	0.84	23.6	15,670	New River, Fayette Co., W. Va.
2.07	5.34	0.72	21.6	15,730	Pocahontas and New River
					EASTERN BITUMINOUS.
4.07	9.21	1.86	37.8	15,230	Elk and Jefferson Cos., Pa., Lower Freeport bed
3.18	6.85	0.92	34.0	15,500	Kanawha Gas Coal, Powelton bed, W.V.
3.19	6.66	0.98	33.5	15,360	" " "
3.59	10.83	1.33	36.2	15,120	Monogahela R., Pa., Pittsburgh bed
4.44	8.29	1.38	36.7	15,180	Youghiogheny River, Pa.
1.82	6.59	1.24	38.8	15,270	Westmoreland Co., Pa., thin vein.
1.07	7.67	1.50	31.8	15,490	Pratt City, Ala., Pratt bed
1.26	6.45	1.55	31.5	15,610	" " "
1.90	4.58	1.05	35.1	15,380	Blocton, Ala., Cataba red ash
					WESTERN BITUMINOUS.
6.76	11.05	2.37	41.7	14,490	Pana, Ill., No. 6 bed, washed nut
7.08	9.38	2.19	41.8	14,550	" " "
10.89	12.38	3.90	48.1	14,110	Staunton, Ill., No. 6 bed, lump
3.28	10.66	4.28	39.6	15,000	Cherokee and Crawford Cos., Kansas, lump
8.30	14.21	3.76	42.6	14,470	Englevale, Kans., Cherokee run-of-mine
3.87	12.67	0.72	42.5	14,760	Las Animas Co., Colo.

*Purchase by Thermal Value.**—Some of the largest central stations and private corporations have adopted as a basis of coal purchase specifications involving the thermal values of the fuel. A specification typical of this class reads as follows:

I. The company agrees to furnish and deliver to the consumer .... at such times and in such quantities as ordered by the consumer for consumption at said premises during the term hereof, at the consumer's option, either or all of the kinds of coal described below; said coals to average the following assays:

KIND OF COAL.			
Of size passing through screen having circular perforations in diameter	—in.	—in.	—in.
Of size passing over a screen having circular perforations in diameter	—in.	—in.	—in.
Per cent of moisture in coal as delivered	—	—	—
Per cent of ash in coal as delivered	—	—	—
B.T.U. per pound of dry coal	—	—	—
From following county	—	—	—
From following State	—	—	—

Coal of the above respective descriptions and specified assays (not average assays) to be hereinafter known as the contract grade of the respective kinds.

II. The consumer agrees to purchase from the company all of the coal required for consumption at said premises during the term of this contract, except as set forth in paragraph III below, and to pay the company for each ton of 2000 pounds avoirdupois of coal delivered and accepted in accordance with all of the terms of this contract at the following contract rate per ton of each respective contract grade, at which rates the company will deliver the following respective numbers of British thermal units for one cent, the contract guarantee.

Kind of Coal.	Contract Rate per Ton.	Contract Guarantee.
....	$............Equal to	..........net B.T.U. for 1c.
....	$............Equal to	..........net B.T.U. for 1c.
....	$............Equal to	..........net B.T.U. for 1c.

Said net B. T. U. for one cent being in each case determined as follows: Multiply the number of B. T. U. per pound of dry coal by the per cent of moisture (expressed in decimals), subtract the product so found from the number of B. T. U. per pound of dry coal; multiply the remainder by 2000 and divide this product by the contract rate per ton (expressed in cents) plus one-half of the ash percentage (expressed as cents).

* J. E. Woodwell, Proc. Am. Soc. for Testing Materials, 1907.

III. It is provided that the consumer may purchase for consumption at said premises coal other than herein contracted for for test purposes, it being understood that the total of such coal so purchased, shall not exceed five per cent of the total consumption during the term of this contract.

IV. It is understood that the company may deliver coal hereunder containing as high as three per cent more ash and as high as three per cent more moisture and as low as 500 fewer B. T. U. per pound dry than specified above for contract grades.

V. Should any coal delivered hereunder contain more than the per cent of ash or moisture or fewer than the number of B. T. U. per pound dry allowed under paragraph IV hereof, the consumer may, at its option, either accept or reject the same.

VI. All coal accepted hereunder shall be paid for monthly at a price per ton determined by taking the average of the delivered values obtained from the analyses of all the samples taken during the month, said delivered value in each case being obtained as follows: Multiply the number of B. T. U. delivered per pound of dry coal by the per cent of moisture delivered (expressed in decimals); subtract the product so found from the number of B. T. U. delivered per pound of dry coal; multiply the remainder by 2000 and divide this product by the contract guarantee; from the quotient (expressed as dollars and cents) subtract one-half of the ash percentage delivered (expressed as cents).

Another form of this kind in force at this time and even more rigid in many particulars as applying to a particular kind of coal virtually specified is of especial interest as indicating a full appreciation of the financial importance of safeguarding the interests of large consumers in the effort to secure the best thermal return for the expenditure. The contract requirements are drawn with a view to procuring a definite kind of coal described as a "good steam, coking, run-of-mine, bituminous coal, free from all dirt and excessive dust, a dry sample of which will approximate the company's standard in the heat value and analysis, as follows":

Carbon	71	per cent
Volatile matter	20	"
Ash	9	"
	100	"
Sulphur	1.5	"
B.T.U.	14,000	

The price paid by the company per ton, for a lighter of coal, is based upon a table of heat values for excess or deficiency of its standard. This table places the arbitrary valuation of 1 per cent

for each 50 B. T. U. excess of deficiency. (If this table is calculated in direct proportion to the price of the coal, that price would evidently be $2.80.) In addition to the corrections for heating value as determined by a Mahler bomb calorimeter, the price paid is subject to deductions for excess of ash, volatile matter, sulphur or dust, or for a shortage in the standard lighter quantity.

Volatile matter and ash are each penalized to the extent of two cents per ton for each one-half of 1 per cent above the standard, while excess of sulphur is penalized to the extent of six cents per ton for the first quarter of 1 per cent excess and four cents per ton for each succeeding quarter of 1 per cent up to 2.5 per cent, above which a deduction of twenty cents per ton is made. A further deduction of seven cents per ton is made if any lighter of coal delivered at the company's docks contains less than 700 tons.

With the respect of business clauses the contract is carefully drawn, and such subjects as bond, payments, deliveries, docking, towing and demurrage, and method of sampling, testing and arbitrating test results are all explicitly covered. The amount of coal consumed by this company, over 350,000 tons per annum, valued at about a million dollars, fully justifies such elaborate contract conditions.

Coal Specifications of Street Railway Companies.—In the coal specifications of the Cleveland Railway Company the standard for heat value per pound of dry coal is 12,610 to 12,759 B.T.U., inclusive. The premiums range upon a graded scale as high as 21 cents per ton above standard price for heat values of 13,960 B.T.U. and above; whereas the penalties range as high as 50 cents per ton for heat values of 10,660 to 10,809.

The standard for ash is placed at from 0 to 15 per cent, with no premium for a minimum amount. For excess ash, however, the penalty reaches 50 cents per ton for 29.1 per cent and over. Likewise a heavy penalty is provided for sulphur. The standard is placed at from 0 to 3.5 per cent and the penalty increases gradually until it is 45 cents per ton, corresponding to 10 per cent and over.

It is further stipulated that if the contractor should fail at any time to supply coal of such quality or quantity as stipulated in the contract, the railway company shall have the right to purchase coal in such quantities as may be needed, at the market rates and in the open market, and collect the additional cost, if there be any, from the contractor. Also, the railway company shall have the right to cancel the contract and relet the work should the contractor fail to fulfil all the terms of the contract.

The specifications of the Interborough Rapid Transit Company provide for the acceptance, without penalty, of coal containing 20

per cent or less volatile matter, 9 per cent or less ash and 1.5 per cent or less sulphur. This is designated as the standard with no premiums for minimum amounts, but with penalties ranging as high as 18 cents a ton for 24 per cent or more volatile matter, 23 cents per ton for 13.5 per cent or more ash, and 12 cents per ton for sulphur up to 2.5 per cent. The premiums for an excess in B.T.U. over the standard of 14,201 to 14,250 run as high as 26 cents per ton for 15,505 B.T.U. per pound of dry coal and the maximum penalty is 45 cents per ton for a heat value of 12,000 B.T.U. or less per pound of dry coal. The average premium and penalty is about 1 cent per ton for each 50 B.T.U. in excess or short of the standard.—*Power,* Oct. 17, 1911.

The Purchase of Coal.*—When coals of the same character are under consideration the heating value may be considered as a correct measure of the value of the coal. When coals of different character are to be compared, the character of the coal as well as the heating value must be considered.

There is often a considerable variation in the quality of coals from the same district, due principally to impurities in the coals or in the methods of mining and preparing the coals for the market.

It is a common practice for one company to operate a number of mines and to ship coal from all of these mines to their customers. It is rarely that coal is equally good in all the mines and, therefore, the customer will receive some good coal and some inferior. It is not practicable in many cases to furnish the coal from one mine.

Some coals may be burned at either high or low rates of combustion without difficulty and with good efficiency, but there are many coals which always give trouble from clinker when burned at high rates of combustion. When burned at moderate rates they may usually be fired so as to give the same percentage of heat to the boiler as the non-clinkering coals.

The influence of the volatile matter on the efficiency depends on the design of the furnace. With a poor furnace and indifferent firing coals containing about 18% volatile matter may give results 10 or 12% higher than coals containing 30% or more volatile matter.

As there is a loss of both time and heat while the fires are being cleaned the presence of large quantities of ash interferes with the proper distribution of air through the fuel and may lower the efficiency.

The moisture not only requires heat to evaporate it into steam, but if the coal is very wet and is fired in large quantities, it may cool the bed of fire and cause an additional loss of unburned gas.

The size of coal is important in many cases. If the coal does not coke and is fine, there may be a large loss of fuel through the grates when burned on inclined grate stokers or on hand-fired grates

* Extracts from a paper by Dwight T. Randall, in Jour. A. S. M. E., March, 1910.

at rates that require frequent breaking up of the fuel bed. If coal is too large more air is admitted than is necessary to burn it properly and if the fuel bed cannot be increased in thickness to overcome this difficulty, there will be a large heat loss. If the coal is fine and the draft is very strong, some of it will be carried off the grate only partially burned.

Fine coal which cakes and forms a porous coke may be burned with good efficiency. If the coal does not coke but packs closely on the fuel bed, it is difficult, if not impossible, to secure a uniform air supply at all parts of the bed and the combustion is poor owing to an excess of air at some points and a lack of air at others.

It has been found possible to design furnaces to burn almost any fuel with reasonably good efficiency based upon the available heat of the fuel. This has been accomplished with tan bark, sawdust, lignite and low grade coals. As a rule inferior coals can be bought much more cheaply on their heating value than the higher grades of coal. In many cases it will be profitable to change the equipment so as to burn slack coal or coals which are below the average quality. It is fully as important to take into account the size and character of coal when automatic stokers are in use as when the coal is hand-fired.

The coal dealer should not be held responsible for results in boiler plants except as influenced by changes in the quality of the coal delivered. A coal which is suited to one plant may not burn well in another, owing to differences in equipment, load condition or to the methods of handling the fires.

The method of taking a sample of coal is fully as important as the manner in which it shall be analyzed and the cause of doubt as to the value of coal analyses has been largely due to ignorance or carelessness in taking samples for analysis.

Methods of Sampling.—The following method of obtaining a sample of coal has been used by a number of different firms and has been found satisfactory. The object in taking a sample is to secure a small portion of the coal which represents as nearly as possible the entire shipment or delivery.

The original sample should preferably be collected in a large receptacle with cover attached, by taking small shovelfuls from many parts of the car, barge or vessel as it is being unloaded, or from as nearly all parts of a pile as possible, care being taken in all cases to secure practically the same amounts from the top, middle and bottom of the coal. The original sample thus taken should amount to 500 lbs. or more, preferably 1000 to 2000 lbs. A separate sample should be taken from each 1000 tons or less delivered. The gross sample thus collected should contain the same proportion of lump and fine coal as exists in the whole shipment. It should be protected from the weather in order to avoid gain or loss in moisture and should be immediately quartered down to a smaller sample, according to the following method.

The large lumps should be broken down on a clean, hard, dry floor with a suitable maul or sledge. The coal should be thoroughly mixed by shoveling it over and over and formed in a conical pile. The pile should then be quartered, using a shovel or board to separate the four quarters. Two opposite quarters should then be rejected and the remaining two broken down to a smaller size, mixed and re-formed in a conical pile and quartered as before. This process should be continued until the lumps are ¼ in. in size or smaller and a one or two-quart final sample remains. *All* of this final sample should immediately be placed in one or more glass or metal cans and sealed air tight. The following table gives the largest sizes allowable in the samples of various weights and the coal should preferably be broken into still smaller sizes before quartering:

Weight of Sample	Should pass through
1000 lb. or over	1½-in. sieve
500 lb. or over	1¼-in. sieve
250 lb. or over	1 -in. sieve
125 lb. or over	¾-in. sieve
60 lb. or over	½-in. sieve
10 lb. or over	¼-in. sieve

The sample should be worked down as rapidly as possible to avoid loss of moisture through exposure to the air. The outside of the can should be plainly marked and a corresponding description placed inside the can.

A sample of coal, taken by an approved method and analyzed by an experienced coal chemist, should show results which, when compared with the true values, are within the following limits:

Moisture	1.00 per cent of the coal as delivered
Ash + or −	0.50 per cent of the dry coal
Sulphur + or −	0.10 per cent of the dry coal
B.t.u. + or −	1.00 per cent of the dry coal

The results will be sufficiently accurate for commercial purposes and within the limits of error of the weights of the coal shipped.

The important items in a specification are as follows:

(*a*) A statement of the amount and character of the coal desired.

(*b*) A statement regarding the conditions for delivery of coal.

(*c*) A statement regarding the disposition which will be made of the coal in case it is outside the limits specified.

(*d*) A statement regarding the corrections in price for variations in heating value, in ash and in sulphur.

(*e*) A blank form on which the dealer may submit the price and the kind and quality of coal which he proposes to furnish.

It is necessary in almost every case to modify the specifications to fit the special conditions in the plant and the fuel which are available.

The importance of testing coal purchased under contract may be illustrated by two recent cases. In Case 1 the coal was guaranteed to be Georges Creek and in Case 2 to be New River.

	Case 1.		Case 2.	
	Guaranteed Analysis as Delivered.	Coal Delivered.	Guaranteed Analysis as Delivered.	Coal Delivered.
Ash in dry coal.......	8.00	12.66	6.00	8.48
B.T.U. in dry coal....	14,250	13,558	14,700	13,981

This method of purchasing coal has been adopted by many of the larger and most progressive consumers of coal. Its advantages are so clearly demonstrated to engineers experienced in power house practice that few who are in a position to purchase large quantities of coal are willing to do so without a guarantee as to its quality. With information as to the coal bed, the district and the mine from which the coal will be furnished and the guaranteed analysis, an experienced engineer can select a coal for the plant which is both suitable and cheap when quality and price are considered.

Spontaneous Combustion of Coal.* —Dust is a dangerous thing in a coal pile, particularly if it is mixed with larger-sized coal which forms air passages to the interior. Spontaneous combustion is brought about by slow oxidation in an air supply sufficient to support the oxidation, but insufficient to carry away all the heat formed. There is a wide variation among coals in friability. This is a large factor in spontaneous combustion. Mixed lump and fine, i. e., run-of-mine, with a large percentage of dust, and piled so as to admit to the interior a limited supply of air, make ideal conditions for spontaneous heating.

High volatile matter does not of itself increase the liability to spontaneous heating.

Pocahontas coal gives a great deal of trouble with spontaneous fires in the large storage piles at Panama. It is reported by large by-product-coke concerns to be more troublesome in this respect than high-volatile gas coals. The high-volatile coals of the west are usually very liable to spontaneous heating, but they owe this

* Technical Paper No. 16, U. S. Bureau of Mines, 1912. H. C. Porter and F. K. Ovitz.

property to the chemical nature of the substances which compose the coal rather than to the amount of volatile matter. A high-oxygen content in coal appears to promote its tendency to spontaneous combustion.

The influence of moisture and that of sulphur upon spontaneous heating of coal are questions not yet settled. Observation by the Bureau of Mines in many actual cases has not developed any instances where moisture could be proven to promote heating. Sulphur, on the other hand, has been shown to have, in most cases, only a minor influence. On the other hand, a Boston company, using Nova Scotia coal of 3 to 4 per cent sulphur, has much trouble with spontaneous fires in storage, but a number of samples taken by the Bureau from exposed piles of this coal in which heating had occurred showed that 90 per cent of the sulphur was still unoxidized. Experiments in the laboratory, passing air over coal at 120 degrees centigrade, have developed enough heat to ignite the coal and no change was found in the form of the sulphur. While not entirely conclusive, these results point to a very minor contribution, if any, on the part of sulphur to spontaneous heating in coal.

Freshly mined coal and even fresh surfaces exposed by crushing lump coal exhibit a remarkable avidity for oxygen, but after a time become coated with oxidized material, "seasoned," as it were, so that the action of the air becomes much less vigorous. It is found in practice that if coal which has been stored for six weeks or two months and has even become already somewhat heated, be rehandled and thoroughly cooled by the air, spontaneous heating rarely begins again.

With full appreciation of the fact that any or all of the following recommendations may under certain conditions be found impracticable, they are offered as being advisable precautions for safety in storing coal whenever their use does not involve an unreasonable expense.

1. Do not pile over 12 feet deep nor so that any point in the interior will be over 10 feet from an air-cooled surface.

2. If possible, store only in lump.

3. Keep dust out as much as possible; therefore reduce handling to a minimum.

4. Pile so that lump and fine are distributed as evenly as possible; not, as is often done, allowing lumps to roll down from a peak and form air passages at the bottom.

5. Rehandle and screen after two months.

6. Keep away external sources of heat even though moderate in degree.

7. Allow six weeks' "seasoning" after mining before storing.

8. Avoid alternate wetting and drying.

9. Avoid admission of air to interior of pile through interstices around foreign objects such as timbers or irregular brick work; also through porous bottoms such as coarse cinders.

10. Do not try to ventilate by pipes, as more harm is often done than good.

CHAPTER IV.

COAL-FIELDS OF THE UNITED STATES.

THE accompanying maps showing the developed coal-fields of the United States are copied from one that was published in the Reports of the Census of 1890.

The long field extending southwesterly from north-central Pennsylvania to near the centre of Alabama is the great Appalachian field, which contains in a narrow strip on its eastern border the semi-bituminous coals, and west of this strip the best varieties of bituminous gas, steam, and coking coals.. East of this field there are several small detached fields, the most important of which are the three anthracite fields of eastern Pennsylvania. To the northwest there is the separate field of Michigan, containing a rather poor quality of bituminous coal. To the west is the Illinois or Central field, extending into Indiana and Kentucky, and containing a great variety of bituminous coals, most of which are inferior to the coals of the Appalachian field. West of the Mississippi the principal field is the great Missouri field covering several States, and having several detached portions reaching into Texas. The coals of this field are mostly of a poor quality. West of the 97th meridian there are a great number of detached fields, mostly of small areas, with every grade of coal from anthracite to lignite. The principal characteristics of the several fields, and the quality of the coal found in each, will be treated of below.

Graphitic Coal in Rhode Island and Massachusetts.— An area of 400 square miles in the central part of Rhode Island and eastern part of Massachusetts, from Newport Neck, R. I., to Mansfield, Mass., contains a variety of anthracite which has been metamorphosed into graphite or graphitic coal. It requires a such high degree of heat for combustion that it can be used only with other combustible material or under a heavy draft. The deposit was worked as early as 1808 at the Porstmouth mine, and at intervals since, but never with profit.

COAL-FIELDS OF THE UNITED STATES EAST OF THE 98TH MERIDIAN.

To face page 98.

COAL-FIELDS OF THE UNITED STATES WEST OF THE 97TH MERIDIAN.

ANALYSES OF RHODE ISLAND AND MASSACHUSETTS COAL.

	Water and Volatile Matter.		Fixed Carbon.	Ash.
Mansfield, Mass.	2 to 4		90 to 92	4
Rhode Island coal	7 to 10		77 to 84	5 to 6
Cranston, R. I.	8.55	3.55	82.25	5.65

The Anthracite Coal-beds of Pennsylvania.—These beds are all in the eastern portion of the State. They are three in number, known variously as First, Second, and Third, as Southern, Middle, and Northern, or as Schuylkill, Lehigh, and Wyoming. The area of the first is 143 square miles, of the second 128 square miles, and of the third 198 square miles—a total of 469 square miles. There are fifteen workable beds in this area, of a total thickness of 107 ft. of coal, the thickness of the measures in which the beds are interstratified being about 3000 feet. The coal in all of the fields follows the general law of increasing in percentage of volatile matter and decreasing in hardness towards the western portion of the fields.

In "Mineral Resources" for 1886 the anthracite fields of Pennsylvania are described as grouped into five principal divisions: (1) The southern or Pottsville field, extending from the Lehigh River at Mauch Chunk southwest to within a few miles of the Susquehanna River north of Harrisburg; (2) the western or Mahanoy and Shamokin field, lying between the eastern head-waters of the Little Schuylkill River and the Susquehanna; (3) the eastern middle or the upper Lehigh field, lying between the Lehigh River and Catawissa Creek, principally in Luzerne County; (4) the northern or Wyoming and Lackawanna field, which lies in the two valleys from which its geographical name is derived; (5) the Loyalsock and Mehoopany field, named from the two creeks whose head-waters drain it. The latter is a small field about 20 or 25 miles northwest of the western end of the northern field.

In addition to this geological division the fields are also subdivided under different names and in a different way for trade purposes, the divisions being known as trade regions. These are: (1) The Wyoming region, embracing the entire northern and Loyalsock fields; (2) the Lehigh region, embracing all of the eastern middle field and the Panther Creek district of the southern field; and (3) the Schuylkill region, embracing the western middle field and all of the southern field except the Panther Creek district.

Size and Quality of Anthracite (Paul Sterling, Trans. Am. Inst. Mining Engrs., 1911)—The following table gives the various sizes, the

diameter of ring over and through which each size is made, and the usual purpose for which it is employed.

COMMERCIAL SIZES OF ANTHRACITE.

Name.	Diameter of Ring.		Use.
	Over.	Through.	
	Inches.	Inches.	
Lump	$6\frac{1}{2}$	....	Locomotive steam coal
Steamboat	$4\frac{1}{2}$	$6\frac{1}{2}$	Blast-furnaces; smiths' forges
Broken	$3\frac{1}{4}$	$4\frac{1}{2}$	Domestic furnace-coal
Egg	$2\frac{5}{16}$	$3\frac{1}{4}$	" "
Stove	$1\frac{5}{8}$	$2\frac{5}{16}$	Domestic range-coal
Nut	$\frac{15}{16}$	$1\frac{5}{8}$	" "
Pea	$\frac{5}{8}$	$\frac{15}{16}$	Domestic furnace-coal
Buckwheat	$\frac{7}{16}$	$\frac{5}{8}$	Boiler, steam
Rice	$\frac{1}{4}$	$\frac{7}{16}$	
Barley	$\frac{3}{32}$	$\frac{1}{4}$	

The following table gives a standard of preparation which is about the average adopted in the anthracite coal-field. The table allows a percentage of "bone," in addition to slate, in the coal; "bone" being defined as a product containing between 40 and 55 per cent of carbon.

STANDARD OF PREPARATION, SHOWING THE PERCENTAGE OF SLATE, BONE, ETC., PERMITTED IN EACH SIZE OF COAL.

May Contain.	Broken.	Egg.	Stove.	Nut.	Pea.	Buck.	Rice.	Barley.
Of slate	1	2	2.5	4	8	10	15	15
Of bone	2	2	4	5	5			
Of next size larger	......	5	5	10	5	8	8	8
Of next size smaller	20	50	50	15	15 B. 15 R.	15	25	

Semi-anthracite in Sullivan Co., Pa.—The Bernice coal-basin lies between Beech Creek on the north and Loyalsock Creek on the south. It is six miles long E. to W., and hardly a third of a mile across. There is 8 ft. of coal in a bed of 12 ft. of coal and slate. The coal of this bed is on the dividing line between anthracite and semi-anthracite, and is similar to the coal of the Lykens Valley district. Nine analyses give a range as follows: Water, 0.65 to 1.97; volatile matter, 3.56 to 9.40; fixed carbon, 82.52 to 89.39; ash, 3.27 to 9.34; sulphur, 0.24 to 1.04. More recent analyses (Trans. A. I. M. E. xiv, 721) give the following:

SULLIVAN CO., PA., COAL.

	Water.	Vol. Matter.	Fixed C.	Ash.	Sulphur.
Working seam................	0.65	9.40	83.69	5.34	0.91
60 feet below seam...........	3.67	15.42	71.34	8.97	0.59

The first is a semi-anthracite, the second a semi-bituminous.

Progression from Bituminous to Anthracite.—In a direction across the basins northward from Bernice, in Sullivan Co., to Gaines, in Tioga and Potter counties, a distance of 50 miles, is seen the transition from bituminous to anthracite coal, the proportion of volatile matter to fixed carbon in the different basins being:

	Volatile Matter.	Fixed Carbon
Gaines, 1 to 1.964, equal to................	33.7	66.3
Blossburg, 1 " 3.494, "	22.3	77.7
Barclay, 1 " 4.094, "	19.6	80.4
Bernice, 1 " 10.289, "	8.9	91.1

At Bernice a semi-bituminous coal underlies the semi-anthracite 60 ft., both beds being found in the same hillside only 60 ft. apart.* In another case a coal-bed has two benches, the upper semi-bituminous and the lower anthracite, with 6 ft of slate bottom. (From reports of Second Geological Survey of Pennsylvania.)

Early Use of Pennsylvania Anthracite Coal.—Pennsylvania anthracite coal was known as early as 1766, and was used in 1768 in the Wyoming Valley by two blacksmiths named Gore. In 1776 several boat-loads were sent to Carlisle, where it was used during the Revolutionary War to manufacture arms. It was not used for domestic purposes until 1808, when Judge Jesse Fell of Wilkesbarre burned it on an experimental grate of hickory withes. He then made an iron grate, and taught the people in the vicinity how to make such grates. In 1793 the Lehigh Coal Mining Co. was formed, which some years later sold a quantity to the city of Philadelphia for the use of a steam-engine at the water-works, then at Broad and Market streets, but it was not used because it "could not be burned." In 1812 Col.

* It will be noted that this condition in Sullivan Co., Pa., is exactly opposite to that found in western Pennsylvania and central Ohio, where the coals mined over a large extent of country show nearly identical composition. See Lord and Haas's tests in the next chapter.

George Shoemaker took nine wagon-loads to Philadelphia, disposed of two or three loads at the cost of handling, and left the rest with different persons for experiment. At the Fairmount Wire and Nail Works the workmen spent a forenoon in fruitless attempts to make a fire with it. At last they closed the furnace doors and went to dinner; returning an hour later, they found the doors red-hot and the furnace all aglow. After that there was no more trouble in burning anthracite. In 1820 the trade was fully established, 365 tons being shipped to Philadelphia in that year.

The failures to burn anthracite in these early days were due to ignorance of the proper conditions for burning it. These are:

1. A very hot fire of wood must first be established.

2. The coal should be laid in a bed several inches deep.

3. The bed of coal must not be poked or otherwise disturbed while beginning to burn.

4. A constant supply of air must be maintained from the grate through the fire.

An interesting account of the early history of the anthracite coal trade will be found in "Mineral Industry" for 1895.

Virginia Anthracite.—In the southwestern part of Virginia occur beds of coal which on analysis prove to be anthracite. They are found in Pulaski and Wythe counties, along the southern border of Little Walker Mountain. The areas are limited and the coals have been greatly disturbed. They do not belong to the true Carboniferous coals, but to the Upper Devonian (Rogers X.) formation, and lie under the true coal-measures of Pennsylvania, Ohio, and northwestern Virginia.

Analyses of seven samples gave:

Water.	Volatile Matter.	Fixed Carbon.	Ash.
0.35 to 0.80	6 to 7.58	85.85 to 89.47	3.97 to 7.35

Anthracite in Colorado.—Anthracite coal of good quality is found in Gunnison Co., Colorado (Hayden's Survey Report for 1874). The coal is not a true Carboniferous anthracite, but is an "altered lignite" of the Post-Cretaceous formation. The quality varies greatly in different beds and even in the same bed in neighboring localities, occuring in all stages of transition from bituminous to hard anthracite. The following are analyses of some of these coals. No. III might be classified as a semi-bituminous coal, and No. VI as a semi-anthracite.

COLORADO ANTHRACITES.

	I.	II.	III.	IV.	V.	VI.
Water	2.00	1.60	4.00	7.40	3.68	1.64
Volatile matter	2.50	3.40	14.00			7.39
Fixed carbon	91.90	88.20	74.00	88.92	91.02	86.60
Ash	3.60	6.80	8.00	3.68	5.30	4.37

Anthracite in New Mexico.—Dr. R. W. Raymond, formerly U. S. Mining Commissioner, in his report for 1870 describes a bed of true anthracite, 4 to 5 feet thick, near Santa Fé, containing 80.5% of fixed carbon, and another, 1½ miles distant, containing 88% carbon and 5% ash.

Bituminous and Semi-bituminous Coal-fields of the United States.

The following notes on the bituminous and semi-bituminous coal-fields and on the quality of coal found in them have been compiled from a variety of sources; among others, the reports of the U. S. Census of 1890, and annual volumes of "Mineral Resources of the United States" and "Mineral Industry," reports of the Geological Surveys of Pennsylvania and other States, and various papers in the Transactions of the American Institute of Mining Engineers.

The Triassic Area comprises what is known as the Richmond basin in Chesterfield and Henrico counties, Virginia, and the Deep River and Dan River fields in North Carolina. Charles A. Ashburner, in "Mineral Resources" for 1886, says that the first coal mined systematically in the United States was taken from the Richmond basin, and that in 1822 about 48,214 tons of coal were produced there, more than twelve times the total amount produced in the Pennsylvania anthracite field in the same year. Its maximum output was reached in 1883, when 142,587 tons were mined.

The Bituminous Coals of the Carboniferous Formation (not including the more recent coals of the Western States) are found in four separate fields or basins, which are shown on the map, viz.: 1. The Appalachian field, extending from Pennsylvania to Alabama, containing 59,105 square miles. The eastern portion of the Appalachian field contains the semi-bituminous coals, which are found in a narrow strip running from northern Pennsylvania through portions of Maryland, Virginia, West Virginia, and Tennessee. 2. The Illinois basin, extending into the western part of Indiana and northwestern

Kentucky, 47,188 square miles. 3. The Michigan basin, 6700 square miles. 4. The Missouri or Western basin, 90,343 square miles, covering portions of Iowa, Nebraska, Missouri, Kansas, Indian Territory, and Arkansas, with an extension into Texas. The coal in this basin is in general not so pure as that in the Appalachian field, and contains a great deal of sulphur.

West of the Missouri there are the lignites and lignitic coals (some of them transformed into bituminous and anthracite) of the Rocky Mountain field, containing the coal areas in the States and Territories lying along the Rocky Mountains, and the Pacific Coast field, embracing the coal districts of Washington, Oregon, and California.

The various fields are described at some length in "Mineral Resources" for 1886, and also in the report for 1894. The latter also contains some historical information regarding the development of these fields. "Mineral Resources" for 1892 contain some interesting contributions from State geologists on the coal-fields of several States, and the 1910 volume contains an excellent paper by E. W. Parker, "The Production of Coal in 1910," with maps of the coal-fields in different States, descriptions of the fields, and a complete list of the publications of the U. S. Geological Survey relating to coal.

Pennsylvania.—The Appalachian coal-field extends over portions of 31 counties. It has an area of about 14,200 square miles in the State.

Blossburg field, Tioga Co. Five beds, A, B, C, D, and E, from 2½ to 5½ feet thick. Coal A is the lowest of the series. Coal B, Bloss bed 4½ to 5½ feet, is the best. Coal C is a sort of a cannel-coal of an inferior grade in this location; farther west it improves.

McIntyre basin, Lycoming Co. The coal-beds are similar to those of the Blossburg region, three of them, E, C, and A, being of workable thickness.

Towanda basin, Bradford Co. One seam also found in the McIntyre basin.

Snowshoe basin, Centre Co. Eight miles in length by four in width. Five seams. A has 6 to 3½ feet, and E 5 feet, of good coal.

Clearfield region, on Moshannon Creek, in Clearfield Co. Three workable seams, 5, 4½, and 4 feet.

Johnstown region, Cambria Co. Five beds, 2½ to 7 feet thick.

Broad Top basin, in Bedford, Huntington, and Fulton counties, 40 miles east of the Alleghany Mountains. The area is 81 square miles. Five workable beds, the principal one being 5 to 10 feet thick.

Salisbury basin, Somerset Co. A short extension of the Cumberland coal-field of Maryland. It contains all the coals of the Lower measures and several square miles of the Pittsburg seam.

Semi-bituminous coal is produced in all the above-named fields.

Main Field of Western Pennsylvania. One large field in the southwestern counties. The several beds are found in different series, known respectively as the Upper Barren, the Upper Productive, the Lower Barren, and the Lower Productive coal-measures, and the Conglomerate series.*

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* The geologists have changed the names of these coal measures, as in the following description, taken from "Mineral Resources," 1910.

The coal-bearing rocks all belong to the Pennsylvania series, and have a total thickness in the southwest corner of the State of about 2600 feet. The great bulk of the coal mined comes from the Allegheny and the Monongahela formations, formerly known as the "Lower" and the "Upper Productive Coal Measures." Below the Allegheny formation is the Pottsville, containing, in the western part of the State, the Sharon and the Mercer coals, which have been worked only in restricted areas. The Allegheny formation, with a thickness of 250 to 350 feet, contains at least seven coal horizons, all of which yield workable coal locally. They are called, beginning at the bottom, the Brookville, Clarion, Lower Kittanning, Middle Kittanning, Upper Kittanning, Lower Freeport, and Upper Freeport coals. It is now definitely recognized that the coals of these horizons do not occur in continuous beds, and in many cases not in exactly the same horizons; yet it is clear that the corresponding geologic horizons mark times of conditions generally favorable for coal formation and that no coal of wide extent is found at other levels. No one of them is continuously workable, but the Lower Kittanning and the Upper Freeport coals are widely workable, and the Lower Freeport has a splendid development over several counties in the northeast part of the field. The Brookville or "A" coal is of workable thickness in spots over a large part of the marginal belt of the coal measures, especially in Jefferson, Clearfield, Centre, Cambria, and Somerset counties. The Clarion or "A′" coal reaches workable thickness in about the same belt, though the two are seldom of workable thickness in the same section. Both of these coals are apt to be impure when thick. The Lower Kittanning or "B" coal is the most persistent, uniform, and reliable of the Allegheny coals, although it is thinner than the Freeport coals, seldom exceeding a thickness of 4 feet. It is exposed in workable thickness and purity in 11 of the counties. The Middle and the Upper Kittanning horizons, "C" and "C′", contain but little workable coal, though the Upper Kittanning shows cannel-coal at a number of points and stands fourth in productivity. The Lower Freeport coal, "D," is finely developed in Clearfield, Jefferson, Indiana, and Cambria counties—in the well-known Moshannon (Clearfield) Reynoldsville-Punxsutawney, and Barnesboro-Patton basins. The Upper Freeport or coal "E" is a variable and complex bed, extending in gross workable thickness over most of its area, although over a considerable part of this territory it is too much broken up and too impure for profitable mining. It appears to be entirely absent in some localities.

As a whole, the Allegheny formation yields about 40 per cent of the total output of bituminous coal in the State.

The Upper Barren measures contain but one seam of commercial importance, the Washington seam, which attains its best development, 3 to 3½ feet, in Washington and Fayette counties.

The Upper Productive Coal-measures contain the great Pittsburgh seam, 6 to 12 feet thick, in Fayette, Washington, Allegheny, Westmoreland, and Greene counties, smaller areas also occurring in Indiana, Somerset, and Beaver counties. The famous Connellsville coke is made from this seam. The Connellsville region is a narrow strip, about 3 miles wide and 60 miles in length. The Pittsburgh seam here affords from 7 to 8 feet of coal. The quality of the coal is intermediate between the semi-bituminous, lying to the east of it, and the fat bituminous coals, to the north and west. The Waynesburg bed, an important seam in Greene, Washington, Fayette, and Westmoreland counties; the Uniontown, in Fayette and Greene counties; the Sewickley and Redstone beds, in Westmoreland and Alleghany counties, are also in the Upper Productive measures.

The Lower Barren measures contain several workable beds of limited area in Indiana, Somerset, Butler, Armstrong, and Beaver counties.

The Lower Productive measures contain the Freeport Lower coal, a bed of great importance in Jefferson, Indiana, Clearfield, Cambria, Armstrong, Centre, and Allegheny counties, and workable in parts of Beaver, Butler, Elk, Blair, Cameron, Westmoreland, and Fayette counties; the Freeport Upper coal, workable in fifteen counties; the Kittanning Upper, or Darlington, bed, consisting partly of cannel and partly of bituminous coal, of workable thickness in parts of Butler, Armstrong, Somerset, Beaver (cannel), Indiana, Jefferson, Elk, and Lycoming counties; the Kittanning Middle, locally workable in But-

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For about 600 feet above the Upper Freeport bed occurs the Conemaugh formation, or "Lower Barren Measures." It contains six or more coals, which, however, are workable only in very restricted areas, their best development being found in the Berlin Basin in Somerset County.

Just above the Conemaugh formation lies the Pittsburgh coal, the most uniform in quality and thickness, and for a given area the most valuable coal bed in the bituminous field of Pennsylvania. Although not of as high a grade as the best Allegheny coals to the east, and although varying greatly in quality from east to west, on the whole the Pittsburgh coal, on account of its thickness, its regularity, its high grade, and its adaptability for the production of coke and illuminating gas, has long been the most famous bituminous coal bed in America. It is confined to the southwestern part of the State. The bed gives 9 feet of available coal over large areas, and seldom runs under 4 feet. Above the Pittsburgh coal occur the Redstone, Sewickley, Uniontown, and Waynesburg coals, which are of good workable thickness locally, but in the presence of the great Pittsburgh coal are but little mined.

ler, Lawrence, Jefferson, Armstrong, Elk, Cameron, and Clarion counties; the Kittanning Lower, workable in twenty-two counties, an excellent coking coal along the Allegheny escarpment, and in the western counties often a good gas-coal; the Millerstown bed, locally workable in Butler county; the Clarion bed, in some of the western counties, usually quite thin; and the Brookville bed "A" of the Allegheny escarpment counties, often a very sulphurous coal.

The Conglomerate series contains the Mercer Upper and Lower coals, workable over limited areas in Lawrence, Jefferson, McKean, Elk, Mercer, and Venango counties; the Quakertown coal, workable over a small area in Mercer County; and the Sharon coal, good but nearly exhausted in Mercer County, and thin and inferior in Warren and Crawford counties.

Exhaustion of Pennsylvania Coal.—M. R. Campbell (Mineral Resources of 1910) estimates the amount of anthracite remaining at 16,640,000,000 tons. If half of it is lost in mining, the rate of production in 1910 would exhaust it all in 99 years. The bituminous coal remaining to be mined is a little over 109,000,000,000 tons, which at the rate of exhaustion in 1910 would last 480 years.

Analyses of Pennsylvania Bituminous and Semi-bituminous Coals.—The analyses given in the two following tables are selected from reports of the Pennsylvania Geological Survey and from various papers

PENNSYLVANIA SEMI-BITUMINOUS COALS.

County.	Number of Samples.	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.	Volatile Matter per cent of Combustible.	Approx. Heating Value per lb. Combustible.
Bradford	7	0.82	16.95	69.26	0.67	12.29	19.7	15,800
Sullivan	12	3.24	13.03	72.74	0.61	10.38	15.2	15,700
Tioga	17	1.65	20.50	67.79	1.26	8.85	23.2	15,750
Lycoming	2	1.06	17.53	72.42	0.84	8.15	19.6	15,700
Centre	1	0.60	22.60	68.71	2.69	5.40	24.7	15,800
Huntingdon	Extremes of	0.47	13.84	72.85	1.98	8.16	15.0	15,700
	5	0.79	17.38	78.46	0.88	4.81	18.6	15,800
Blair*	9	1.06	27.27	60.69	2.31	8.66	31.0	15,550
Cambria:								
Lower bed, B	7	0.74	21.21	68.94	1.98	7.51	23.5	15,750
Upper bed, C	1	1.14	17.18	73.42	1.41	6.58	19.0	15,800
Clearfield:								
Upper bed, C	9	0.70	23.94	69.28	1.42	4.62	25.7	15,700
Lower bed, D	8	0.81	21.10	74.08	0.42	3.36	22.2	15,800
Somerset	30	1.15	19.77	67.78	1.61	9.67	22.6	15,800

* According to these analyses the Blair Co. coals should not be included in the semi-bituminous class. They are higher in volatile matter than the semi-bituminous coals of Cambria Co., which is west of Blair Co.

PENNSYLVANIA BITUMINOUS COALS.

County.	Number of Samples.	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.	Volatile Matter, per cent of Combustible.	Approx. Heating Value per cent of Combustible.
Jefferson	26	1.21	32.53	60.99	1.00	3.76	34.8	15,300
Indiana	29	0.98	29.26	58.74	1.73	9.46	33.3	15,400
Westmoreland	27	1.14	32.27	59.23	1.50	5.97	35.3	15,200
Fayette	12	0.95	29.75	60.47	1.79	7.04	33.0	15,400
Potter	3	1.72	32.28	55.32	1.01	9.67	36.8	15,100
McKean	11	2.25	34.49	46.25	2.97	14.02	42.6	14,600
Clarion	7	1.97	38.60	54.15	1.19	4.10	41.6	14,700
Armstrong	1	1.18	42.55	49.69	2.00	4.58	46.1	14,000
Butler	11	1.91	39.88	48.97	1.97	7.22	44.9	14,200
Lawrence	14	2.11	40.45	52.51	1.37	3.25	43.5	14,500
Beaver	20	1.96	39.04	50.20	2.00	6.96	43.7	14,500
Washington	21	1.16	37.11	50.99	2.06	8.72	42.1	14,700
Greene	17	1.14	35.74	51.75	1.79	9.10	40.8	14,800
Youghiogheny River*	..	1.03	36.49	59.05	0.81	2.61	37.9	15,100
Connellsville †	..	1.26	30.10	59.61	0.78	8.23	33.5	15,400

* The Youghiogheny River is in Allegheny, Westmoreland, and Fayette counties. The coal mined along this river is a favorite coal in the Ohio and Mississippi River markets.

† Connellsville is in Fayette County. The coal of this region is chiefly used for making coke for blast-furnace and foundry purposes.

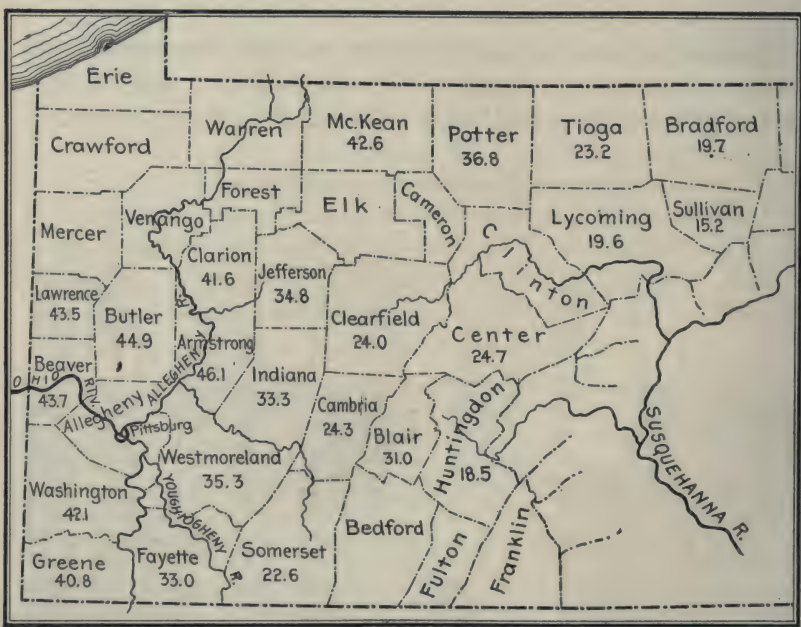

FIG. 5.—SEMI-BITUMINOUS AND BITUMINOUS COAL REGION OF PENNSYLVANIA.

(The figures under the names of the counties represent the percentage of volatile matter in the combustible, as given in the table of analyses.)

in the Transactions of the American Institute of Mining Engineers. The figures of approximate heating value per lb. of combustible are interpolated from the table on p. 56 showing the relation of heating value to the percentage of volatile matter in the combustible. For the semi-bituminous coals they are probably within 2 per cent of being accurate; for the bituminous coals within 4 per cent.

The figures of volatile matter per cent of combustible are entered on the accompanying map under the names of the several counties. It will be seen that there is a general tendency for the volatile matter to increase towards the west and north. Blair County seems to be an exception. The boundary line along which the semi-bituminous coals grade, more or less rapidly, into the bituminous, and the location of beds of bituminous coals within the limits of the portion of the field which contains the semi-bituminous coals, as far as the author is aware, have not yet been laid down on any map.

The difference between the semi-bituminous and the bituminous coals of Pennsylvania is an important one economically. The former have on the average a heating value per pound of combustible about 6 per cent higher than the latter, and they also burn with much less smoke in ordinary furnaces.

The following tables show the great similarity in composition in the coals of the upper and lower coal-measures in the same geographical belt or basin. They also show the tendency of the volatile matter to increase to the westward:

ANALYSES FROM THE UPPER COAL-MEASURES (PENNA) IN A WESTWARD ORDER.

Localities.	Moisture.	Vol. Mat.	Fixed Carbon.	Ash.	Sulphur.
Anthracite	1.35	3.45	89.06	5.81	0.30
Cumberland, Md	0.89	15.52	74.28	9.29	0.71
Salisbury, Pa	1.66	22.35	68.77	5.96	1.24
Connellsville, Pa	......	31.38	60.30	7.24	1.09
Greensburg, Pa	1.02	33.50	61.34	3.28	0.86
Irwin's, Pa	1.41	37.66	54.44	5.86	0.64

ANALYSES FROM THE LOWER COAL-MEASURES IN A WESTWARD ORDER.

Localities.	Moisture.	Vol. Mat.	Fixed Carbon.	Ash.	Sulphur.
Anthracite	1.35	3.45	89.06	5.81	0.30
Broad Top	0.77	18.18	73.34	6.69	1.02
Bennington	1.40	27.23	61.84	6.93	2.60
Johnstown	1.18	16.54	74.46	5.96	1.86
Blairsville	0.92	24.36	62.22	7.69	4.92
Armstrong Co	0.96	38.20	52.03	5.14	3.66

Maryland Semi-bituminous Coal.—The Cumberland coal-field, in Allegheny Co., Md., is 30 miles long and of an average breadth of $4\frac{1}{2}$ miles. Its northern end reaches into Pennsylvania and its southern extremity into West Virginia. The main bed is from 12 to 14 ft. thick. The coal is one of the best steam-coals mined in the United States. It is jet black and glossy; is friable, and becomes pulverized in transportation and handling. There are several other beds from 2 to 6 ft. in thickness, the whole series of the Pennsylvania coal-measures being found in the district.

"Mineral Resources" of 1910 estimates the amount of coal that still remains in an area of 455 square miles in Maryland as 7,802,000,000 tons, or over 900 times the exhaustion, including waste, in 1910.

*Elk Garden and Upper Potomac Coal-fields.**

On the extreme fringe of the great Appalachian coal-basin is a long, narrow, detached coal-field, which is, in some respects, one of the most important in the United States. This field, about 90 miles long by $2\frac{1}{2}$ to 16 miles wide, extends from the southwest corner of Somerset County, Pa., through Allegany and Garrett counties, Md., Mineral, Grant, and Tucker counties, W. Va., into Randolph County, W. Va. In this distance four distinct subdistricts are recognized, the Wellersburg in Pennsylvania, and Cumberland-Georges Creek in Maryland, and the Elk Garden and the Upper Potomac in West Virginia. It is the nearest to tide-water of all the bituminous coal-fields which supply the great coal markets of the northern Atlantic seaboard, and its coal-beds are so situated as to permit a well-nigh unlimited increase of production should the trade of these markets demand it.

This great coal-field has sometimes been termed the Cumberland coal-field, but the name is now more appropriately applied to a coal (that of the Big Vein) which is not mined throughout the entire district. As the district is watered chiefly by the Potomac River and its tributaries, and as most of the mining is along the banks of that stream, the name "Potomac Basin" has been suggested for this entire coal-field; the distinctive and well-known names of the several sub-basins, however, being still retained.

The general course of this basin is northeast and southwest. It is

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* Abstract from a paper by Joseph D. Weeks, read before the American Institute of Mining Engineers, 1894.

hemmed in by the Alleghany Front Mountains on the east and the Backbone Mountains on the west. Its general shape from Pennsylvania to near the southern border of Tucker County, W. Va., is that of a wedge, very narrow in Pennsylvania, only 2½ miles wide at the State line, and widening as the mountains draw away from each other, until at the point named in Tucker County, it is some 16 miles wide.

The northern end of this field passes through the western part of Alleghany County and a portion of the eastern part of Garrett County, Maryland, and from it the entire coal product of Maryland is obtained.

Virginia.—There are several detached coal-fields in the Mesozoic rocks east of the Alleghany Mountains. They are described by O. J. Heinrich, in Trans. A. I. M. E., 1878, vol. vi. The Richmond basin, 189 square miles, chiefly in Powhatan and Chesterfield counties, west of Richmond, is the most important. It contains two workable beds, the lower 3 to 5 ft. thick, and the upper 20 to 40 ft. thick. The coal is chiefly bituminous, containing 30 per cent or upwards of volatile matter in the combustible, but at Carbon Hill semi-bituminous is found, also "carbonite" or natural coke, corresponding in analysis to semi-anthracite.

Semi-anthracite coal, with about 84 to 86 per cent fixed carbon in the combustible, is mined in Pulaski and Montgomery counties.

The Appalachian semi-bituminous coals are found in the southwestern portion of the State, in Tazewell County, on the West Virginia border, and the bituminous coals in the southwestern corner of the State near the Kentucky line.

The Pocahontas coal-field embraces parts of Buchanan, Dickinson, Lee, Russell, Scott, Tazewell, and Wise counties, at the southern edge of the Flat Top region, including the Clinch valley field, containing the Lower Productive measures of the Appalachian field.

The Pocahontas Flat Top coal-measures are above the water-level, in seams ranging from 5 to 13 ft. in thickness, extending through an area estimated to contain not less than 300 sq. miles. Pocahontas semi-bituminous coal is from the Lower coal-measures and contains from 18 to 20 per cent of volatile matter. It is mined in Tazewell, Wise and Lee counties, Va., and in Mercer and McDowell counties, W. Va., the adjoining counties to the north. The veins dip to the north and west, and the extension of the Ohio division of the Norfolk and Western Railroad north to the Ohio River and the road west to the Cumberland Mountains pass through the Middle and

Upper measures, thus opening up coal of greater volatile matter, bituminous, splint and cannel.

The development of this now famous region began in 1881, but not until 1883 was any coal shipped out of the country. In 1893 the Pocahontas field was open in Wise County, Virginia, and 1905 in Lee County, and development work has been done in Dickinson, Russell and Buchanan counties. In 1910 the production of Wise County was three times that of Tazewell County.

North Carolina.—Semi-anthracite is found in two unimportant beds, 18 inches thick, in the Dan River field, 40 miles long, 4 to 7 miles wide, of which 8 miles are in Virginia. The Deep River field, 30 miles long by 3 wide, contain five beds, all differing in character, ranging from bituminous coal to an impure plumbago, as shown by the following analyses:

	Volatile Matter.	Fixed Carbon.	Ash.
Bituminous, 3 ft. thick	32.8	63.8	4
Semi-bituminous, 1 ft. thick	23.6	72.6	4
Anthracite, 3 ft. thick	6.6	83.8	9.6
Plumbaginous slate, 2 ft. thick	....	10.4	78
Plumbago, 4 ft. thick	....	18.2	74

The Cummock or Egypt mines in the Deep River field were operated from 1889 to 1905, producing 23,000 short tons in 1902, 17,300 tons in 1903, 7000 tons in 1904, and 1557 tons in 1905. No coal has been produced in the State since 1905.

West Virginia.—Out of 54 counties only 6 are destitute of coal. The quality is semi-bituminous in the eastern portion of the coal-bearing district and bituminous in the western. The first coal-field is the Potomac basin, an extension of the Cumberland semi-bituminous coal-field of Maryland. The Monongahela basin embraces five beds, of which the Pittsburg, 9½ ft. of clear coal, is the most important. This is a gas-coal, and makes a hard coke, but is high in sulphur. The New River coal-field lies in Fayette and Raleigh counties, bordering the New River from 40 miles from Quinnimont to Kanawha Falls. It contains both semi-bituminous and bituminous steam, coking and gas-coals of excellent quality. The Kanawha coal-field lies along the Kanawha River and its branches, below the junction of the New and Gauley rivers. The coal is bituminous, and includes gas-coals, cannel and

hard splint coal. It is largely mined for shipment down the Ohio River. The Pocahontas field lies in the southwestern corner of the State, in McDowell and Mercer counties, and extends across the State line into Virginia. All of the Pocahontas coal is a high-grade semi-bituminous. As a steam coal it ranks with the best Cumberland, Md., and Clearfield, Pa., coals, and as a coke producer it rivals the Connellsville, Pa., coal.

The amount of coal remaining in West Virginia in 1910 is estimated at about 149,000,000,000 tons, and at the rate of production in 1910, adding 50 per cent for loss it would last for about 160 years.

WEST VIRGINIA ANALYSES, FROM PRIME'S REPORT OF THE CENTENNIAL EXHIBIT.

	Moisture.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
Piedmont, Mineral Co	0.82	19.36	75.86	0.71	3.96
Austen, Preston Co	0.11	31.12	66.29	0.64	2.48
Kingwood, top of bed	0.34	31.47	65.66	0.58	2.53
Monongahela Co., Upper Freeport bed	0.63	28.06	54.28	0.77	17.03
" " Pittsburg bed	0.39	38.64	54.77	2.54	6.20
" " Redstone seam	0.37	37.88	54.36	2.87	7.39
" " Sewickley seam	0.44	35.78	54.31	3.10	9.47
" " Waynesburg seam	0.74	35.36	56.35	0.71	7.55
Despard, Harrison Co	....	40.00	53.30	....	6.70
Murphy's Run, Harrison Co	1.58	37.10	49.08	2.84	9.40
Wood's Run, Ohio Co	1.74	42.97	50.99	2.88	4.30
Hartford, Putnam Co	3.43	44.38	46.88	1.57	5.30
Osborn, Wayne Co	2.30	40.43	48.72	0.76	8.55
CANNEL COAL.					
Falling Rock Creek, Elk River	....	43.20	50.80	....	6.00
Peytona, Boone Co	....	46.00	41.00	....	13.00

ANALYSES OF WEST VIRGINIA COALS, NEW RIVER REGION.

	Moisture.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
Quinnimont lump	0.76	18.65	79.26	0.23	1.11
" slack	0.83	17.57	79.40	0.28	1.92
Fire Creek	0.61	22.34	75.02	0.56	1.47
Londale (Sewell)	1.03	21.38	72.32	0 27	5.27
Nuttalburg	1.35	25.35	70.67	0.57	2.10
Hawk's Nest	0.93	21.83	75.37	0.26	1.87
Ansted	1.40	32.61	63.10	0.74	2.15

Eastern Kentucky.—The Appalachian field extends into Eastern Kentucky, including fifteen counties and portions of five others, covering altogether 10,270 square miles. The following analyses are from Owen's Geological Survey of the State:

No. of Bed.	Locality.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
1	Lawrence County.............	3.50	36.30	57.30	2.90	1.15
2	Carter County................	4.10	34.60	55.25	4.77	1.41
3	Greenup County..............	3.56	35.00	52.34	9.02	2.59
4	Carter County (cannel)........	0.60	66.30	28.30	4.80	1.32
5	Lawrence County.............	3.20	32.30	53.00	11.50	1.20
6	Boyd County..................	3.27	33.77	54.51	8.91	1.56
7	Coalton County..............	5.19	32.04	55.59	6.71	1.68

The following analyses of Eastern Kentucky coals are taken from a report by Capt. H. S. Hodges, Corps of Engineers, U. S. A., January, 1900,* on a Survey of the Big Sandy River, West Virginia and Kentucky, including Levisa and Tug Forks:

	No. of of Analyses.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Vol. Mat. % of Combustible.
LAWRENCE COUNTY:							
Peach Orchard coal	2	4.60	35.70	53.28	6.42	1.08	40.1
McHenry coal....	1	3.24	36.56	54.95	5.24	1.19	40.0
		3.36	37.05	52.82	5.55	1.22	41.2
JOHNSON COUNTY:							
Bituminous coals..	5	2.66	38.04	56.30	3.00	1.29	40.3
		1.20	41.80	46.00	11.00	0.96	47.6
Cannel coals......	8	1.80	49.20	44.00	5.00	0.85	52.8
		1.20	64.39	26.36	8.05	1.67	71.0
FLOYD COUNTY:	9	3.80	33.80	60.60	1.80	0.48	35.8
		1.30	36.70	51.70	10.30	1.36	41.5
PILE COUNTY:	37	1.80	26.80	67.60	3.80	0.97	28.4
		1.60	41.00	50.37	7.00	0.03	42.9
Average of	37	.....	34.77	58 61	.....	.....	37.2
Cannel coal.......	1	0.58	54.07	40.64	4.70	0.87	57.1
MARTIN COUNTY:	3	1.46	32.60	62.68	3.26	.....	34.2
		2.47	34.18	55.03	8.32	1.17	38.3

The analyses here given are selected from those in the original report, to show the range of quality, as indicated by the percentage of

* H. R. Document No. 326, 56th Congress, 1st Session.

volatile matter in the combustible, of the coals of the several counties.

The relative location of the counties, and the percentage of volatile matter per pound of combustible in the bituminous (not cannel) coal in each county, as given in the table, are shown in the accompanying map.

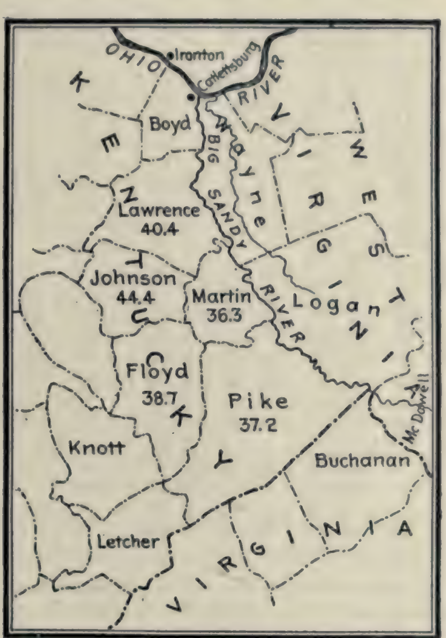

FIG. 6.—BIG SANDY COAL REGION OF EASTERN KENTUCKY.

The author commends to State geologists and others who have occasion to make reports on the extent and quality of coal deposits the method of mapping both the location and the quality which is shown here and also on page 109. The reports of the U. S. Geological Survey, of the U. S. Census, and of the Geological Surveys of the several States would be of greater value than they now are if they contained such maps.

The eastern Kentucky coals are mostly high-grade gas or coking coals, with some cannel coal. For lack of transportation the production has been small. In 1910 out of 14,623,319 short tons mined in the State, 6,279,024 tons are credited to eastern Kentucky.

ANALYSES OF KENTUCKY COAL.

County.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur	Volatile Matter Per cent of Combustible	B.T.U. per Lb.	
							Dry Coal	Combustible.
Bell	2.07	35.03	58.69	4.21	0.95	37.4	14,852	15,520
Harlan	2.88	35.64	56.90	4.58	0.78	38.5	14,692	15,419
Hopkins	8.19	40.03	43.09	8.69	3.62	48.2	13,375	14,473
Johnson	4.46	39.99	51.00	4.55	1.01	44.0	13,988	14,687
Letcher	2.40	35.84	58.29	3.47	0.73	38.1		
Muhlenburg	8.75	38.18	43.81	9.26	4.01	46.6	13,233	14,728
Ohio	9.32	41.37	40.06	9.25	2.95	50.8	13,308	14,820
Pike	2.34	31.42	61.43	4.81	0.64	33.9	14,219	14,956
Union	7.00	32.87	54.02	6.11	1.15	37.9	14,482	15,500
Webster	5.23	37.24	50.09	7.44	3.35	42.6	14,142	15,318
Whitley	2.40	39.01	53.24	5.35	1.54	42.3	14,023	14,836
Martin	3.10	31.78	54.74	10.38	0.88	36.7		
Morgan	....	42.03	.....	8.65	1.10			
Floyd	2.41	34.70	57.65	5.24	0.66	37.6		
Menifee	4.18	35.78	54.80	5.24	0.94	39.5		
Magoffin	2.94	37.57	53.46	6.03	0.90	41.3		
Wolf	3.62	35.36	54.67	6.35	1.83	39.3		
Pulaski	2.22	35.27	54.87	7.64	1.85	39.1		
Rock Castle	3.52	33.77	54.99	7.72	1.77	37.1		
Laurel	2.38	35.30	58.46	3.86	1.12	37.6		
Breathitt	3.95	37.63	50.57	7.85	1.24	42.7		
Perry	....	38.04	.....	5.54	0.82			
Lawrence	4.24	38.04	49.49	8.23	1.44	43.5		
Leslie	....	36.91	.....	6.62	0.57			
Knox	1.50	34.54	59.16	4.80	0.93	36.9		
Jackson	2.70	37.11	52.31	7.88	1.11	41.5		

NOTE.—The above analyses are from reports of U. S. Geological Survey, Kentucky Geologcal Survey and private reports. Contributed by Mr. Howard N. Eavenson, Gary, W.Va., 1914.

Western Kentucky.—The great central coal-field extends south of the Ohio river into the western part of Kentucky. It underlies the whole or portions of eight counties. It is mined chiefly in Hopkins, Muhlenberg, Ohio, and Webster counties. (See page 121.)

Tennessee.—The Appalachian field crosses the eastern part of Tennessee in a comparatively narrow belt, 71 miles wide at the northern boundary and narrowing to 50 miles at the southern or Alabama and Georgia State line. The workable coal-area is confined to what is known as the Cumberland table-land. About 4400 square miles are contained in the area, which is embraced in nineteen counties. There are nine seams, of which six are over 3 feet in thickness. The coals range from semi-bituminous to bituminous, and some are of

excellent quality. In Campbell County is a part of the famous Jellico steam-coal field. The Sewanee vein is one of the most important ones in the State and is worked extensively in Grundy County. Coke of high grade is made from the coal of this seam. A comprehensive paper on the Tennessee coal-fields, by Prof. J. M. Safford, was published in "Mineral Resources," 1892.

ANALYSES OF TENNESSEE COALS.

	Moisture and Volatile Matter.	Fixed Carbon.	Ash.
Addison's Creek, Cumberland Mountains.	9.00	83.22	7.78
Crow Creek	14.00	77.70	8.30
Sewanee Mining Co.	14.21	79.56	6.25
Tracy City	29.00	65.50	5.50
Marion, Upper Seam	38.00	59.50	2.50
Etna	21.39	74.20	4.41
Chattanooga	26.80	63.90	9.30
Coal Creek, Anderson	40.00	55.00	5.00

Georgia.—The Appalachian coal-field enters the extreme northwest corner of the State, the coal-measures occupying an area of from 150 to 170 sq. miles. The coal is similar in quality to that of Tennessee. One analysis, from Dade Co., gave: Moisture, 1.20; volatile matter, 23.05; fixed carbon, 60.50; ash, 15.16; sulphur, 0.84. The coal production of Georgia decreased from the maximum figure of 416,951 short tons in 1903 to 177,245 tons in 1910. The decrease is attributed to scarcity of labor.

Alabama.—The southern extremity of the Appalachian coal-field covers about 6000 sq. miles, in the northern part of the State. There are three separate basins: the Warrior, 5000 sq. miles, extending nearly across the State; the Cahaba, nearly 400 sq. miles, to the southwest of the Warrior field, and the Coosa, 350 sq. miles, east of the Cahaba and on the northwest side of the Coosa River. The coal-measures contain ten or twelve beds of workable thickness. The Cahaba Basin coals are the best in the State. The larger bed is 12 ft. thick, of good coal. Besides these three basins there is the Plateau field, east of the Warrior basin, whose resources are comparatively small.

The following analyses are from the reports of E. A. Smith, State geologist:

ALABAMA COALS.

Bed.	County.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Cahaba Basin:						
Cahaba	Shelby	1.66	33.28	63.04	2.02	.53
McGinnis		1.91	32.65	63.91	1.53	.63
Moyle		1.93	32.84	59.64	5.59	3.78
Little Pittsburg		2.05	33.47	62.20	2.28	.64
Conglomerate		2.13	30.86	64.54	2.47	1.48
Helena		2.54	29.44	66.81	1.21	.53
Montevallo		2.13	27.03	66.22	4.62	.50
Warrior Basin:						
Townley	Walker	3.01	29.08	63.35	4.56	.71
Jagger	"	3.09	29.04	56.54	11.33	.57
Burnett's	Marion	3.69	35.38	58.52	2.41	1.73
Pratt Co.'s	Upper Jefferson	1.47	32.29	59.50	6.73	1.22
"	Lower "	1.53	30.68	63.69	4.10	.61

Ohio.—The Appalachian coal-field in Ohio covers more than 12,000 square miles in the eastern and southeastern portions of the State, its length being about 180 miles and its width about 80 miles. The coals are all of the bituminous variety, are known in general terms as block coal, gas-coal, cannel-coal, etc., and by many special names, as Mahoning Valley, Hocking Valley, Salineville, etc., according to the producing localities. Thirteen workable beds are found along the Ohio River, but only two of them, No. 6, or the "Great Vein" of Perry Co., and No. 8, or the Pittsburg bed, are found workable over great areas. No. 1, the "block coal" of the Mahoning Valley, called elsewhere "Massillon" and "Jackson" coal, is of great excellence wherever found. It is thinly laminated, and is broken by transverse cleavages into cubical blocks, whence its name of "block coal."

ANALYSES OF OHIO COALS FROM DIFFERENT BEDS (NEWBERRY).

Coal, No.	Locality.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
I.	Mahoning Co	2.47	31.83	64.25	1.45	0.56
II.	Holmes Co	2.15	28.65	52.70	16.50	2.13
III.	"	3.90	40.50	49.95	5.65	1.55
III.	Yellow Creek	2.50	36.60	56.30	4.60	2.05
IV.	Coshocton Co. (Cannel)	1.50	44.40	44.50	9.60	1.72
IV.	Stark Co	7.00	30.80	59.50	2.70	0.65
V.	Columbiana Co	1.15	40.45	53.75	4.65	3.51
VI.	"	1.60	29.29	64.50	4.00	2.80
VI.	Muskingum Co	3.47	37.88	53.30	5.35	2.24
VI.	Jefferson Co	1.40	30.90	65.90	1.80	0.98
VII.	Saline Co	1.70	34.30	59.50	4.50	1.63
VII.	Carroll Co	2.80	30.20	64.10	2.90	1.23
VIII.	Harrison Co	2.44	32.36	59.92	5.28	2.62

"Mineral Resources," 1910, names the following as the important productive coal beds: No. 1, Block, or Sharon Coal; No. 2, Wellston; No. 5, Lower Kittaning; No. 6, Middle Kittaning; No. 7, Upper Freeport; No. 8, Pittsburgh; Pomeroy; Meigs Creek. The Hocking Valley Coal of No. 6 bed mined in Perry, Athens and Hocking counties is celebrated as a free-burning coal for steam and domestic purposes.

The following are average figures for some Ohio coals by Lord and Haas. See Chapter V, on "Heating Value of Coal."

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Upper Freeport Bed	1.93	37.35	51.63	9.10	2.89
Middle Kittanning Bed (Hocking Valley)	6.59	35.77	49.64	8.00	1.59
Jackson Co	8.17	35.79	52.78	3.25	1.13

The following table of analyses and heating values of Ohio coals has been contributed by Mr. Howard N. Eavenson. (1914.)

ANALYSES OF OHIO COAL.

County.	Seam.*	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	B.T.U. per Pound.	
							Coal.	Combustible.
Washington	a	3.17	37.71	47.88	11.23	5.29	12,497	14,601
Scioto	b	6.80	37.92	45.94	9.34	3.45	11,839	14,118
Mahoning	c	5.23	36.86	53.19	4.72	2.17	13,504	14,997
Jefferson	c, d	4.06	35.68	51.90	8.36	3.08	12,960	14,798
Vinton	b, e	4.82	39.98	45.52	9.68	3.95	12,364	14,461
Hocking	e	7.09	35.76	51.01	6.13	1.72	12,523	14,548
Athens	d, e	6.37	35.57	49.80	8.25	2.31	12,267	14,369
Perry	c, e	6.57	36.95	48.70	7.77	2.85	12,305	14,367
Gallia	d, f, g	7.07	34.86	47.07	11.19	3.58	11,608	14,168
Morgan	a, d	4.78	38.51	46.46	10.24	4.62	12,085	14,223
Noble	a	3.50	37.52	47.34	11.63	5.58	12,325	14,355
Belmont	a, d	3.90	35.93	49.74	10.27	3.83	12,539	14,636
Harrison	a, d	4.78	35.71	51.09	8.42	2.59	12,661	14,586
Meigs	f	6.51	35.04	48.05	10.40	2.46	11,948	14,380
Jackson	b, c	5.60	38.34	46.11	9.94	4.30	12,092	14,319
Coshocton	e, g	5.04	39.15	48.82	7.00	4.01	12,638	14,298
Muskingum	c, e	4.99	39.96	46.39	8.66	4.62	12,429	14,394
Lawrence	b, c, e, g	7.39	34.66	47.11	10.83	2.85	11,727	14,341
Holmes	e	7.31	34.92	53.56	4.21	1.00	12,514	14,143
Stark	e	5.82	38.78	47.90	7.45	3.87	11,864	13,847
Columbiana	e	3.60	36.16	55.64	4.60	1.76	14,020	15,272
Carroll	e	3.76	39.11	50.34	6.79	3.06	13,028	14,566
Tuscarawas	d, e	4.22	39.80	49.24	7.24	3.94	12,825	14,404
Guernsey	d	6.24	38.32	53.99	8.42	3.34	13,716	14,859

* Names of Seams: *a*, Meig's Creek. *b*, Clarion. *c*, Lower Kittaning. *d*, Pittsburgh. *e*, Middle Kittaning. *f*, Pomeroy. *g*, Upper Freeport. The percentage of volatile matter in the combustible ranges from 39.4 (Columbiana Co.) to 46.3 (Muskingum Co.).

The Northern or Michigan Coal-field.

The coal deposits of Michigan are detached from those of any other State, and form what is known as the Northern field. The area

is about 6700 square miles, the central point being near the town of St. Louis, in Gratiot County, and the southern boundary passing a few miles south of Jackson, in Jackson County. Beyond this to the south there are several detached patches of productive coal-measures. The greatest thickness of the measures is found along a line extending from Ionia County to Saginaw, the thickest coal-beds lying along Six Mile Creek. There is one seam of bituminous coal, 3 or 4 ft. thick, and toward the centre of the basin there are several other beds. One analysis gives: Moisture, 2; volatile matter, 49; fixed carbon, 45; ash, 2; sulphur, 2. The principal operations are carried on near the city of Jackson, in Jackson County, but these are small when compared with other States.

The Michigan coals are of inferior quality when compared to those shipped by lake and rail into the State, and the imported coals were sold so cheaply until about 1897, that the development of the Michigan field was insignificant. In that year the production reached 223,592 tons. The annual production then rapidly increased. In 1907 it was 2,035,858 tons, and in 1910, 1,534,967 tons. The quantity of coal in the State is estimated at about 12,000,000,000 tons.

The Illinois Coal-basin.

(Indiana, Illinois, and Western Kentucky.)

Indiana.—The Illinois coal-field extends into the western part of Indiana, covering an area of 6500 square miles, distributed through 26 counties, in 18 of which coal is produced on a commercial scale. The coal supply of the State is estimated at nearly 44,000,000,000 tons, or enough at the rate of production in 1910, allowing a loss of 35 per cent, to last about 1800 years. The following analyses are given by the State Geological Survey:

ANALYSES OF INDIANA COALS.

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.
Caking Coals.				
Parke Co.	4.50	45.50	45.50	4.50
Sullivan Co. coal M	2.35	45.25	51.60	0.80
Clay Co.	7.00	39.70	47.30	6.00
Spencer Co., coal L.	3.50	45.00	46.00	2.50
Block coals.				
Clay Co.	8.50	31.00	57.50	3.00
Martin Co.	2.50	44.75	51.25	1.50
Daviess Co	5.50	36.00	53.50	5.00

The following ultimate and proximate analyses, credited to Noyes, McTaggart, and Craven, are taken from Poole's "Calorific Power of Fuels":

Locality.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Fixed Carb.	Vol. Mat.
Brazil.........	70.50	4.76	16.29	1.36	1.39	8.98	6.28	50.30	34.49
Lancaster.....	71.41	5.56	18.42	1.54	0.62	12.66	2.68	47.22	37.64
New Pittsburg.	62.88	5.07	13.06	1.01	7.46	6.83	13.30	39.93	39.92
" " .	65.26	5.17	13.25	1.17	5.88	5.89	11.48	40.40	42.23
Shelburn......	66.86	5.30	15.69	1.50	2.57	8.63	9.05	43.45	38.82

All of the Indiana coal is classed as bituminous. That along the eastern edge of the field is known as block or semi-block coal, breaking through cleavage planes into rectangular blocks. It is very pure, dry, and non-coking. The rest of the coal is called gas or coking coal.

Western Kentucky.—The Illinois coal-field extends into the northwestern portion of the State, including ten counties and portions of five others, having an area of 3888 square miles of coal-measures. There are, in places, twelve beds, but the number varies with the locality. The following analyses are from Prime's Centennial Report on Coal:

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Coal A (average)...........	4.15	33.14	55.71	7.00	1.87
" B (average)...........	3.65	38.40	51.87	6.06	3.12
" C (gas-coal layer)......	4.60	40.10	51.35	3.95	1.49
" D (average)...........	3.82	35.31	52.11	8.41	3.33
" J (Christian Co.)......	3.70	32.56	50.04	13.70	3.72
" L (average)...........	4.23	33.21	54.19	8.35	1.50
Breckenridge cannel........	1.44	62.40	28.20	7.96	2.44

The following are from the Geological Survey of Kentucky, 1884, Western Coal-Field, D.:

	No. of Samples.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Nolin River District	3	3.40 to 4.70	30.66 to 33.24	51.70 to 54.94	11.06 to 11.70	1.95 to 2.54
Muhlenberg Co....	7	3.60 to 7.06	30.60 to 38.70	50.50 to 58.80	3.40 to 9.20	0.79 to 4.57
Hancock Co.......	7	3.30 to 7.46	33.14 to 43.40	45.56 to 55.20	4.20 to 11.00	1.32 to 4.04
Ohio Co..........	5	3.70 to 5.30	30.70 to 45.70	45.00 to 55.30	3.16 to 14.20	1.24 to 3.13
Breckenridge Cannel	4	0.64 to 1.44	54.40 to 62.40	27.00 to 32.00	7.96 to 12.30	..... 1.89

The Nolin River district embraces portions of Grayson, Edmonson, Hart, and Butler counties.

Illinois.—The coal-field of Illinois occupies an area of 35,600 square miles, or nearly two-thirds of the area of the State. The coal-measures contain six beds of workable size, with a total thickness of 24 ft., but the beds are irregular, often wanting, and often containing an inferior quality of coal. In the DuQuoin district, Perry Co., two seams, V and VI, 6 to 7 ft. thick, are worked within 75 ft. of the surface. In the Big Muddy district, Jackson Co., the coal occurs near the surface. The lower seams produce a good block coal. From the Belleville district, St. Clair Co., St. Louis obtains most of its bituminous coal. Coal seam VI, 5 to 7 ft. thick, is principally worked. The lower seams contain more sulphur and the quality varies. Other large producing districts are at Neelysville, Danville, and La Salle. The latter is of importance from its proximity to Chicago. There are three workable beds, VI, 4½ to 5 ft.; V, 3 to 9 ft., usually 6 ft.; II, 4 ft. The coal of the upper bed, No. VI, is light, dry, and free-burning. No. V is a purer coal. No. II is most highly bituminous, cakes in burning, is high in sulphur, and throws off heavy soot. In the Wilmington district, Will Co., there is a workable seam of coal which is largely used for household and steam purposes. The Illinois coals are generally high in moisture, and are often very high in sulphur and ash. When burned in ordinary furnaces they produce great volumes of black smoke. Recent analyses of Illinois coals (says "Mineral Resources," 1910) show them to contain an average of about 12 per cent moisture, 10 per cent ash, 37 per cent volatile matter, 39 per cent fixed carbon, and 3 per cent sulphur. The proportions vary from region to region, and even from mine to mine. The estimated coal supply of the State in 1910 is about 230,000,000,000 tons, or sufficient to last about 3000 years at the present rate of production, allowing one-third for waste.

Range of Variation in Illinois Coal.—The St. Louis tests show a range of heating value of six samples of Illinois coal of from 13,767 to 14,674 B.T.U. per lb. combustible, or less than 7 per cent. The figures in the following table, omitting Nos. 9*a*, 25*a* and 28*a*, which are probably erroneous, range from 13,469 to 14,830 B.T.U. per lb. combustible, or 10.1 per cent of the smaller value.

A large table of Illinois Coals by Counties published by the Green Engineering Co., gives for each of 40 counties the average, maximum and minimum figures of heating value in B.T.U. per lb., moisture, ash, volatile matter and fixed carbon, with the number of analyses

ILLINOIS COALS.*

No.	County.	Town.	Air-dry Coal.				Pure Coal.		
			Seam.	Moisture.	Ash.	Sulphur.	Volatile Matter.	Fixed Carbon.	B.T.U. per Pound.
1	Bureau	Ladd	2	6.60	8.04	2.70	45.24	54.76	13,793
2*a*	Christian	Pana	6	8.06	18.66	3.45	48.91	51.09	13,694
2*b*	"	Assumption	1	7.74	12.72	2.60	45.59	54.41	14,641
3*a*	Clinton	Trenton	7	9.47	15.28	1.12	39.84	60.16	13,663
3*b*	"	Breese	6	8.10	14.24	3.40	43.78	56.22	14,416
4*a*	Fulton	Norris	5	11.78	14.18	1.93	44.84	55.16	14,238
4*b*	"	Cuba	5	7.70	9.77	3.10	47.48	52.52	14,576
5*a*	Grundy	So. Wilmington	2	11.44	5.36	2.10	44.58	55.42	14,412
5*b*	"	Braceville	2	9.70	31.18	3.55	46.56	54.54	14,623
6	Henry	Kewanee	6	9.99	7.03	2.57	45.79	54.21	13,584
7	Jackson	Murphysboro	1	4.96	4.39	0.62	38.20	61.80	14,653
8	Knox	Etherly	6	10.16	25.00	2.48	48.10	51.90	14,157
9*a*	La Salle	Kangley	7	7.68	8.50	3.24	48.69	51.31	12,535
9*b*	"	Streator	7	5.52	5.40	3.07	47.26	52.74	14,661
10*a*	Livingston	Cardiff	2	10.26	12.02	2.96	47.01	52.99	13,917
10*b*	"	Fairbury	5	6.57	10.00	2.20	47.22	52.78	14,677
11*a*	Logan	Lincoln	5	10.44	8.58	2.44	48.01	51.99	13,546
11*b*	"	"	5	10.64	15.00	3.17	49.46	50.54	14,614
12	McLean	Bloomington	3	5.64	16.46	3.10	48.85	51.15	14,617
13	Macon	Niantic	5	11.01	15.16	3.35	46.74	53.26	13,469
14*a*	Macoupin	Mt. Olive	6	9.62	14.55	3.86	45.11	54.89	13,626
14*b*	"	Greenridge	6	10.24	5.30	1.98	47.31	52.69	14,434
15*a*	Madison	Edwardsville	6	7.76	14.40	4.74	47.44	52.56	14,130
15*b*	"	Collinsville	6	8.26	11.06	3.09	47.52	52.48	14,556
16*a*	Marion	Odin	6	8.52	9.82	3.00	45.43	54.57	13,638
16*b*	"	Sandoval	6	5.51	11.94	2.60	44.59	55.41	14,560
17*a*	Marshall	Wenona	2	10.94	2.32	0.79	42.18	57.82	13,995
17*b*	"	"	2	10.31	13.14	2.67	43.75	56.25	14,331
18*a*	Menard	Middletown	5	10.37	19.20	3.13	47.02	52.98	13,914
18*b*	"	Greenview	5	9.46	8.11	2.41	45.64	54.36	14,255
19*a*	Mercer	Sherrard	1	7.84	18.39	4.78	49.79	50.21	13,748
19*b*	"	"	1	9.60	8.82	3.02	48.25	51.75	14,446
20	Montgomery	Litchfield	2	9.22	5.96	1.77	45.67	54.33	14,265
21	Peoria	Holles	2	8.04	7.80	3.13	48.87	51.13	14,153
22	Perry	Du Quoin	6	7.24	10.04	3.04	46.81	53.19	14,250
23*a*	Randolph	Tilden	6	8.68	7.73	3.07	44.34	55.56	13,786
23*b*	"	"	6	7.17	13.15	3.13	43.55	56.45	14,344
24	St. Clair	French Village	6	8.12	16.21	4.00	46.83	53.17	13,892
25*a*	Saline	Eldorado	5	3.70	15.80	2.40	41.17	58.83	13,150
25*b*	"	Harrisburg	5	5.68	8.90	1.18	39.02	60.98	14,830
26*a*	Sangamon	Auburn	6	10.42	6.46	2.73	47.54	52.46	13,750
26*b*	"	Dawson	5	12.56	9.93	2.14	43.99	56.01	14,326
27	Shelby	Moweaqua	5	9.19	10.16	1.47	45.65	54.35	13,959
28*a*	Vermillion	Catlin	7	9.90	5.02	2.00	47.90	52.10	12,162
28*b*	"	Danville	7	8.00	19.47	3.40	48.02	51.98	14,617
29	Will	Braidwood	2	11.44	4.26	1.95	43.04	56.96	13,406
30*a*	Williamson	Lauder	7	6.35	17.80	1.14	53.80	46.20	13,834
30*b*	"	Herrin	7	5.00	10.62	2.22	37.64	62.36	14,607

* From Bulletin No. 3 of the Illinois Geological Survey.

for each county from which the average maximum and minimum figures are given. The range of figures for the 40 counties are as follows:

	Heating Value Per lb.	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.
Maximum.	10,137 to 13,252	5.20 to 16.30	9.22 to 38.80	28.96 to 46.00	46.87 to 66.50
Minimum .	6,316 to 11,372	1.12 to 10.64	1.20 to 15.30	18.40 to 36.15	30.00 to 52.61
Average . .	9,746 to 11,779	2.67 to 14.10	4.80 to 21.47	26.97 to 39.77	41.33 to 56.04

The table is to be interpreted thus: In 40 counties the maximum heating value of all the samples tested ranged from 10,137 to 13,252 B.T.U. per lb., and the minimum value from 6316 to 11,372, etc. The highest heating value in the whole state is 13,252 B.T.U. per lb., and the lowest, 6316, is less than half the highest. The moisture ranges from 1.12 to 16.30% and the ash from 1.20 to 38.80%. The table would have been more useful if it had given the maximum, minimum and average values of the heating value per lb. of combustible for each county, together with the maximum, minimum and average figures for ash and moisture, for each county.

For the purpose of valuing a certain carload or cargo of coal as received, the heating value per lb. of an average sample is important, but for the purpose of studying the coals of a district and comparing them with coals of another district, the proximate analysis and the heating value of the coal as received, are unimportant, except in that these furnish the basis for the calculation of the heating value per lb. of combustible and the ratio of volatile matter to the total combustible, which together with the average moisture and ash in the coals as received are the data most needed for comparison.

The Missouri Coal-basin.

(Iowa, southeastern Nebraska, Missouri, eastern Kansas, Arkansas, Oklahoma, Texas.)

The separation of the Western coal-field, of which Missouri forms an important part, from the Illinois or Central field is made by the Mississippi River and its immediate valley. At one place near the northern border of the Illinois field the present course of the Mississippi cuts through it, a small portion of the Central field being found across the river in Iowa. The two fields are really the same, the barren valley being a narrow one, and in it isolated bodies of coal are found both in Iowa and Missouri. It has been customary, however, to consider them separately.

Iowa.—The Missouri coal-basin occupies nearly one-half of the State. The coal-measures are divided into upper, middle, and lower, the latter of which contains the productive seams, two in number. They are of irregular thickness, sometimes reaching 5 ft. An average of 64 analysis made by the State geologist gives: Moisture, 8.57; Volatile matter, 39.24; Fixed carbon, 45.42; Ash, 6.77.

Four analyses by Forsyth, given below, show a wide range of quality:

Locality.	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Volatile Matter, per cent of Combustible.
Chisolm..................	9.18	40.42	39.58	10.82	50.5
Flagler's..................	9.48	40.16	37.69	12.31	51.6
Hiteman..................	4.99	35.27	25.37	34.37	58.0
Keb......................	9.81	37.49	44.75	7.95	45.6

The coal from Hiteman appears to be a cannel-coal very high in ash. The coal-bearing formations of Iowa cover an area of approximately 20,000 square miles, of which 13,000 may be considered potentially productive under present conditions and considerably more in future periods when the fuel supplies of the world shall have suffered greater depletion. The total coal remaining is estimated at nearly 29,000,000,000 tons, or about 2400 times the exhaustion in 1910.

Missouri.—The coal-measures are contained chiefly in the northern and western portions of the State. An arm of this territory, however, follows the course of the Missouri River eastward for a short distance in the central part of the State, and some coal is also found in the vicinity of St. Louis. The total area included is estimated at about 25,000 square miles, distributed over fifty-seven counties in whole or in part. All of the coals are of the bituminous variety, with the exception of some limited deposits which approach cannel-coal in character. The bituminous coals have, as a rule, a high percentage of ash compared with the best coals of this character. They are comparatively soft, and deteriorate by exposure or much handling. They also usually carry considerable sulphur in the form of pyrites.

There are 16 seams in three measures, of which seven are of workable thickness. Analyses, by C. G. Brodhead, are as follows:

ANALYSES OF MISSOURI COALS.

County.	Moisture.	Volatile. Matter.	Fixed Carbon.	Ash.	Sulphur.	Vol. Mat. % of Comb.
Ray	10.05	38.55	45.40	6.00	2.41	45.9
Pettis	3.95	33.10	46.26	16.69	4.41	41.7
St. Louis	9.55	38.28	42.99	9.18	....	47.1
Henry	5.14	37.91	46.82	10.13	....	44.7
La Fayette	6.36	36.28	47.80	9.56	....	43.1
Johnson	7.29	42.27	46.95	3.49	....	47.4
Lincoln	8.50	39.50	46.45	5.55	2.63	45.9
Carroll	2.97	36.36	47.83	12.84	....	43.2
Saline	6.02	40.33	42.09	11.56	....	48.9
Livingston	5.38	42.27	44.98	7.37	....	48.4
Nodaway	3.53	42.72	40.71	13.04	....	51.2
Callaway	7.43	38.90	45.85	7.82	....	45.9
Andrew	8.94	34.75	45.38	10.93	....	43.4
Cass	7.80	33.20	55.75	3.25	....	37.3
Charlton	5.82	38.01	54.53	1.64	....	41.1
Macon	12.05	40.75	43.50	3.70	....	48.4

On account of the relatively poor quality of the Missouri coal as compared with that of Illinois its production has been restricted to the needs of local markets. The annual tonnage increased from 2,240,000 short tons in 1882 to 4,238,586 tons in 1903. In 1909 the production was 3,756,530 tons, and in 1910, 2,982,433, the decrease in 1910 being due to a long strike of the miners. The coal supply of the State is estimated to approximate 40,000,000,000 tons.

Kansas.—The Kansas coal-measures form a part of the great Western field which passes through the eastern half of the State from Iowa and Missouri into the Indian Territory, with an outlying area of cretaceous lignite to the west and in the northern central part of the State. The main portion of the field occupies, approximately, one-fourth the area of the State.

The coal-measures consist of three kinds of rock formations—sandstones, limestones, and shales. In these are inclosed the beds of coal, which do not occupy anywhere more than one-twentieth of the thickness assigned to the coal-measures, and over large parts of the area there is no coal at all. A few square miles, with one bed of coal 30 inches thick, would be a rich district, and there are several such districts in eastern Kansas. The bottom of the lower coal-measures is the richest horizon of the formations. It is in this horizon, not far from the Spring River boundary, that we have the Weir City and Scammon coal-field, of Cherokee County, and the neighboring coal-fields of Frontenac and Pittsburg, in Crawford County. The thickest and best seam of coal in Kansas is the Cherokee bed, found in Chero-

kee, Crawford and Labette counties. It extends from Oklahoma, entering the State near Chetopa, and runs across the southeast part of Labette County, the west and northwest parts of Cherokee, and southeast part of Crawford, and enters Missouri. A few miles north of Columbus the coal-mining region begins, and we have a series of mining towns—Scammon, Weir City, Cherokee, Fleming, Frontenac, Pittsburg, Arcadia, Minden—around which the coal seam, whose average thickness is over 40 inches, is worked. About 91 per cent of the total production of the State is mined in this district. The coal is of a better grade than that found in adjacent States.

A second important district is that adjacent to Leavenworth and Atchison in the northeastern part of the State, where a thin bed is found. It produces about 6 per cent of the total output of the State. A third district yielding about 3 per cent of the total is that of Osage and adjacent counties, in which a bed 20 to 22 inches thick is mined. The total supply of the State is estimated to approximate 7,000,000,000 tons.

The following figures showing the range of analyses and heating values of Kansas coals are from Engineering Bulletin No. 3 of the University of Kansas, 1913.

Number of Samples.	Southern Kansas Coals.	Central Kansas Coals.	Leavenworth Coals.
Volatile matter, per cent of combustible	33.05 to 39.80	37.50 to 45.05	38.40 to 42.30
Moisture in coal	1.05 to 4.95	5.10 to 8.00	1.90 to 9.10
Ash in dry coal	7.05 to 28.20	7.20 to 14.05	6.40 to 22.40
Sulphur in dry coal	2.46 to 7.07	3.12 to 6.52	2.56 to 5.40
B.T.U. per lb. combustible	13,660 to 14,850	12,000 to 12,960	12,730 to 14,580

Arkansas.—The coal-measures cover an area of 9043 square miles along the course of the Arkansas River in the western part of the State. Two beds have been opened, but only the lower is of workable thickness. The best coal yet found in the State is the Spadra, in Johnson County, 3½ feet thick in some places. The following analyses are given by Macfarlane:

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Vol. Mat. % of Comb.
Sebastian Co	1.40	12.35	82.25	4.00	13.1
Long's	3.80	10.70	84.10	1.40	11.3
Yell Co	3.00	11.40	80.40	5.20	12.4
Johnson Co. (11 in.)	2.00	7.75	88.75	1.50	8.0
Crawford Co. (1 ft.)	1.00	15.20	80.80	3.00	15.8
Spadra Creek	0.50	7.90	85.60	6.00	8.4

The Arkansas coals range from semi-anthracite in the eastern part of the field to lignite in the western.

Arkansas coals are all more or less soft and friable, and not well adapted to long transportation. The characteristic is variable in different openings. They all burn freely and make little smoke or soot. For reaching the best results, however, a grate with small openings is necessary, as these coals are liable to decrepitate and to fall through the grate.

The production of coal in Arkansas was 1,205,479 short tons in 1898, 2,670,438 tons in 1907, and 1,905,958 tons in 1910. The remaining supply in 1910 is estimated at approximately 1,750,000,000 tons of bituminous and semi-anthracite, and 90,000,000 tons of lignite. The lignite areas have not been developed.

Oklahoma.—The total area underlain by workable coal is estimated at 10,000 square miles. At present the entire production is from what were formerly known as the Cherokee, Creek and Choctaw nations of Indian Territory, the last named contributing by far the largest portion. H. M. Chance (Trans. A. I. M. E., 1890) says:

The Choctaw coal-field is a direct westward extension of the Arkansas coal-field, but its coals are not like Arkansas coals, except in the country immediately adjoining the Arkansas line.

In the Mitchell basin, about 10 miles west from the Arkansas line, coal recently opened shows 19 per cent volatile matter; the Mayberry coal, about 8 miles farther west, contains 23 per cent volatile matter; and the Bryan Mine coal, about the same distance west, shows 26 per cent volatile matter. About 30 miles farther west, the coal shows from 38 to 41½ per cent volatile matter, which is also about the percentage in coals of the McAlester and Lehigh districts.

ANALYSES OF OKLAHOMA COALS.

	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Mitchell Basin	1.06	19.03	71.74	7.53	0.65
Grady Basin	1.79	40.21	51.79	4.88	1.33
McKinney District	1.71	38.67	51.48	7.14	1.01
Krebs, McAlester Bed	1.80	37.17	53.40	6.73	0.90
Lehigh mines	4.32	40.51	48.47	8.10	2.60
Atoka	6.66	35.42	57.52	6.60	3.73
Choctaw Nation	1.59	23.31	66.85	8.25	1.18
Cherokee	3.62	29.51	48.09	14.78	4.00
"	4.07	27.67	42.12	20.20	5.94

"Mineral Resources" for 1889 says of the coals of the McAlester bed mined at McAlester, Krebs, and Alderson, and the Grady bed mined at Hartshorne, "These coals compare favorably with the best gas-coals mined in the country (as comparison with standard Pittsburg coal will show), and they are by far the best coals now mined in the Southwest, if not indeed the best mined west of the Mississippi River. They are in every way vastly superior to Kansas, Missouri, and Iowa coals."

Texas.—A detached portion of the great Missouri coal-field covers the northeastern portion of the State for about 6000 square miles. The coal is a regular bituminous of the Carboniferous age. Some beds are from 3 ft. to 6 ft. thick. The coal is usually of poor quality, high in ash and sulphur. Three analyses gave the following:

Localities.	Moisture.	Vol. Mat.	Fixed Carbon.	Ash.	Sulphur.
Young Co.	10.00	30.75	46.59	11.96	0.70
Fort Worth.	14.42	30.03	42.53	13.02	1.47
" "	4.60	34.72	49.27	11.41	1.56

Analyses by Dr. W. B. Phillips (Min. Res., 1910) show a much greater range of composition. Eleven coals show moisture from 2.8 to 11.0 per cent, ash (in the dry coal) 3.07 to 26.34 per cent, volatile matter, per cent of combustible, nine coals, 40.4 to 47.4 per cent, one 57.0 and one 58.7 per cent, the two last being cannel-coal, containing 5.65 and 5.72 per cent hydrogen in the dry coal with 10.03 and 12.18 per cent oxygen, 3.00 and 2.50 per cent nitrogen, and 2.25 and 2.09 per cent sulphur. One of the coals had as high as 4.24 per cent sulphur.

Cannel-coal and semi-anthracite have also been found in Texas. In the Cretaceous and Laramie coal-fields of the Rio Grande, near Eagle Pass, bituminous coal of good quality is found. It is superior to the Carboniferous coals of the State, but to the eastward the beds are lignite and impure. Lignites, mostly of very poor quality, containing 10 to 20 per cent moisture even when sun-dried, are found in many deposits in the eastern part of the State. The San Tomas, Webb Co., coal, which has the appearance of being an altered lignite, is a very serviceable fuel, and is largely used in Laredo and on the Mexican National Railroad.

The estimated supply of bituminous coal in Texas approximates

8,000,000,000 short tons and of lignite 23,000,000,000 tons. The production in 1910 was bituminous 978,498 tons; lignite 864,858 tons.

Bulletin No. 189 of the University of Texas, 1911, on "The Composition of Texas Coals and Lignites," gives analyses and heating values of about 50 samples of Texas coals from different districts. They show a wide range of variation in composition. In 17 samples taken at the mines the moisture ranged from 3.46 to 13.44 per cent, averaging 7.40 per cent. In 21 samples received from mining companies the moisture was from 2.30 to 11.00 per cent, averaging 5.82 per cent. Some of these may have been partially air-dried. The following analyses of dried coal are selected to show the range of composition. Figures in the second place of decimals are omitted

No.	Volatile Matter.	Fixed Carbon.	Ash.	S.	C.	H.	O.	N.	B.T.U. per lb. Combustible.*	B.T.U. per lb. Coal as Received.†	Moisture in Sample.
3	54.0	38.0	8.0	2.3	71.0	5.7	10.0	3.0	13,190	12,315	2.30
5	39.2	57.7	3.1	1.8	74.7	5.1	13.7	1.6	12,420	11,500	8.20
43	29.9	38.6	31.5	0.6	51.2	3.7	11.8	1.2	12,980	10,600	3.64
1518	50.0	40.6	9.4	2.6	69.5	5.6	11.3	1.5	14,180	11,052	4.09
1520	36.5	44.3	19.2	1.4	64.1	4.6	8.9	1.8	14,300	11,149	9.40
1528	33.0	40.9	26.1	5.0	60.3	4.1	2.6	1.8	15,400	11,171	5.31
Av. of 17	37.2	45.1	17.3	2.4	64.8	4.6	9.0	1.9	14,560	11,245	7.40
Av. of 21	39.1	43.6	17.3	2.0	62.8	4.7	11.0	2.3	13,580	10,558	5.82

No. 3, Cannel Coal, Webb Co., Nos. 5 and 1520, Eagle Pass, Maverick Co. No. 43, Olmos run-of-mine. 1518, Minera, Webb Co. 1528, Keeler, Palo Pinto Co.

* Calculated from the ultimate analyses. † By Parr calorimeter.

The analysis and the heating value of No. 1528 are remarkable, and indicate it to be cannel coal. The figure obtained by the Parr calorimeter, reduced to combustible, is 15,970.

The composition of the ash of Texas coal varies widely. Analyses of the ash from the 17 mine samples gave: Silica 29.1 to 65.3, av. 46.0; alumina 13.1 to 41.1, av. 25.9; oxide of iron 4.0 to 28.0, av. 16.1; lime, trace to 22.1, av. 6.0; magnesia 0 to 2.3, av. 0.7; sulphuric acid, trace to 15.0, av. 4.4.

The Bulletin above named states that there are three well-recognized coal fields in Texas, two on the Rio Grande and one in North Central Texas, west of Fort Worth. The two on the Rio Grande are in Maverick Co., with Eagle Pass as the chief town, and

Webb Co., with Laredo as the chief town. The total workable coal area is about 8200 square miles, with an additional area of 5300 square miles that may contain workable beds. The production of the Rio Grande fields in 1910 was 215,328 tons, and that of the north central field 913,619 tons. The total production of lignite in the State in 1910 was 979,232 tons; and it is rapidly increasing. For analyses of lignites see page 137.

Coals West of the Ninety-seventh Meridian.

Colorado Coals.—The Colorado coals are of extremely variable composition, ranging all the way from lignite to anthracite. G. C. Hewitt (Trans. A. I. M. E., xvii. 377) says: The coal-seams, where unchanged by heat and flexure, carry a lignite containing from 5 to 20 per cent of water. In the southeastern corner of the field the same have been metamorphosed so that in four miles the same seams are an anthracite, coking and dry coal. In the basin of Coal Creek the coals are extremely fat, and produce a hard, bright, sonorous coke. North of Coal Basin half a mile of development shows a gradual change from a good coking coal with patches of dry coal to a dry coal that will barely agglutinate in a beehive oven. In another half mile the same seam is dry. In this transition area, a small cross-fault makes the coal fat for twenty or more feet on either side. The dry seams also present wide chemical and physical changes in short distances. A soft and loosely bedded coal has in a hundred feet become compact and hard without the intervention of a fault. A couple of hundred feet has reduced the water of combination from 12 to 5 per cent.

ANALYSES OF COLORADO COALS.

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Sunshine, Colo., average....	2.8	36.3	37.1	23.8	......
Newcastle, " "	1.7	37.95	48.6	11.6	......
El Moro, " "	1.32	38.23	55.86	3.59	......
Crested Buttes, "	1.10	23.20	72.60	3.10	......
Lenox, Huerfano Co.......	2.92	41.18	45.36	10.54	1.39
Rouse, " "	2.66	36.71	51.41	9.22	1.37
Chicosa, Las Animas Co....	0.20	28.94	64.51	6.35	0.27
Victor. " " " ...	1.26	36.40	53.10	9.24	1.11
Fairmount vein, La Plata Co.	1.25	39.71	52.90	6.14	......
Porter vein, La Plata Co...	0.63	34.70	57.30	7.37	0.74

The Trinidad-Raton coal field, the Colorado portion of which is located in Las Animas County (the southern part of the field is in New Mexico) is the most important producer in the State. Las

Animas County produces nearly 50 per cent of Colorado's total, which was 11,973,736 short tons in 1910. The coal fields in Colorado lie along the lower flanks and among the foot hills of the mountains, in three groups known as the eastern, the park, and the middle groups. —"Mineral Resources," 1910.

In production of coal, Colorado ranks first among the States west of the Mississippi River, and seventh among all the coal-producing States. The estimated total supply in 1910 is 371,500,000,000 tons, equal to about 740 times the production of the whole United States in that year.

New Mexico.—The coals of New Mexico, like most of those of the Rocky Mountain region, are of cretaceous age and vary from anthracite to sub-bituminous. The former occupies only limited areas and its production is less than 2 per cent of the total. Of the total coal production of the State (3,508,321 tons in 1910), over 75 per cent was from the Raton field in Colfax county, the southern extension of the Trinidad field of Colorado. The coal of this field is a true coking coal. There are several small detached areas in the southeastern portion of the State which contain bituminous coal, and in the northwestern part of the State, covering portions of Rio Arriba, San Juan and McKinley counties and containing the producing districts of Gallup and Monero. There is a large area of coal, chiefly sub-bituminous ("black lignite"). At Monero the coal is bituminous. The estimated quantity of coal in the ground in 1910 (not including fields whose boundaries are unknown) is 163,700,000,000 tons.

ANALYSES.

	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
White Oaks, Lincoln Co.....	2.35	35.53	50.24	11.88	0.61
Vermejo Pass..............	3.27	23.73	59.72	13.28	......
Placer anthracite..........	2.90	3.18	88.91	5.21	......

Wyoming.—About 50 per cent of the area of the State is underlain by coal-bearing formations, and the estimated tonnage of the coal in the ground exceeds that of any other State with the possible exception of North Dakota. The largest field is the Powder River field between the Black Hills and the Bighorn Mountains. It is the southern extension of the great Fort Union coal region of Montana and North Dakota, and extends from the North Platte

River to the Montana line. Of the total area of about 15,000 square miles at least 11,000 square miles is underlain by coal beds more than 3 ft. thick. The next largest field is the Green River Basin, in the southwestern part of the State, at least 4800 square miles of which contains workable coal. Other and smaller fields are Bighorn Basin, Wind River Basin, Hannah, Ham's Fork and Mount Leidy.

The coal-bearing formations extend from the base of the upper Cretaceous to near the middle of the Tertiary. As a rule the older the formation the better the coal. The coal mined in Wyoming is bituminous and sub-bituminous. The estimated total supply in 1910 is nearly 424,000,000,000 short tons, or over 800 times the rate of production in the whole United States in 1910.

Analyses and heating values of various coals in Wyoming are given on pages 69 and 160.

Montana.—The coals of Montana are all of Cretaceous age.* They embrace a wide variety of true bituminous coals, found only in or near the mountains, and the inferior lignites whose seams form prominent parts of the series of rocks that underlie the Great Plains country. These lignites have been mined at a few localities, but their low heating power and rapid crumbling unfit them for general use, and the bituminous coals have occupied the market. The lignites differ from the true coals in two important particulars: they contain a large amount of moisture and they crumble upon exposure soon after mining. The moisture makes them of low heating power, and their rapid crumbling unfits them for transportation and is a serious detriment in burning. An average analysis of the lignites of eastern Montana shows: Water, 12-15; volatile carbon, 40-45; fixed carbon, 30-35; ash, 5-10.

The bituminous coals of Montana occur in small isolated fields within the mountain region and in a great belt of coal land that extends along the eastern front of the Rocky Mountains.

The character of the coals varies widely in different seams and at

* The coal beds of Montana range in age from Lower Cretaceous to Fort Union (Eocene, Lower Tertiary). Coal formed in Cretaceous time is of better quality than the later deposit, but the Tertiary beds are thicker and cover a much greater area. The coals are bituminous, sub-bituminous, and lignite, some of the first named producing a fair variety of coal. It is estimated that within this State 34,000 square miles are underlain by coal beds more than 2 ft. in thickness.—"Mineral Resources," 1910.

different fields. Long and short-flamed, coking and non-coking coals occur sometimes in adjoining seams of the same mine. As a whole the coals contain a high percentage of ash, and would not rank high in more favored localities. Some of the coals, however, are as pure as the best of Wyoming or Colorado fuels.

The supply of coal in the ground in Montana in 1910 is estimated at 303,000,000,000 short tons.

Utah.—The Green River coal-basin contains, according to Clarence King's "Geological Exploration of the 40th Parallel," "a practically inexhaustible supply of coal." Beds from 7 to 25 feet thick are discovered at intervals over 500 miles, and from their ordinary gentle dip may be mined with unusual ease. Two analyses are as follows:

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Castledale........	3.43	42.81	47.81*	9.73	....
Cedar City........	3.50	43.66	43.11*	5.95	....

* Includes sulphur, which is very high. Coke from Cedar City analyzed: Water and volatile matter, 1.42; fixed carbon, 76.70; ash, 16.61; sulphur, 5.27.

The areas in Utah known to contain workable beds of coal aggregate 13,130 square miles. The coal-fields are important and widely distributed. The largest and commercially most important region is the great Uinta Basin which lies along the southern side of the Uinta Mountains and extends to the southeast as far as Crested Butte, Gunnison County, Colo.

Washington.—The developed coal-fields lie chiefly in a comparatively narrow belt, running nearly due north and south, through the western portions of Whatcom, Skagit, Snohomish and King counties into Pierce and Thurston counties. Some distance to the east of the southern end of this belt, in Kittitas County, extensive operations have been carried on for a number of years. The main belt extends along the Cascade Range, and important mines have been opened on both the eastern and western slopes of the range. Coal is found also in other localities, notably in Lincoln, Spokane, Cascade, and Okanogan counties. The coals of the State embrace lignite, sub-bituminous and bituminous, and some natural coke and anthracite have been observed. The bituminous coking coals of Washington are the only coking coals on the Pacific slope of the United States. The coal remaining in the State in 1910 is estimated at 19,900,000,000 short tons.

ANALYSES.

Localities.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Bellingham Ba	8.39	33.26	45.59	12.66	......
Seattle...........	11.66	45.98	35.49	6.44	0.43

A very complete report on the coals of Washington is given in Bulletin 474 of the U. S. Geological Survey, 1911. The coal of the State ranges from low-grade sub-bituminous to anthracite. In general, anthracite and bituminous coal occur nearer the axis of the Cascade Mountains, and sub-bituminous coal farther from the range and nearer the center of the Puget Sound depression. The coal in Cowlitz County is brownish black and approaches to a true lignite, but it contains much less moisture than the typical lignite of North Dakota. The coal of Kittitas and Pierce counties is bituminous. Anthracite is found in Lewis County, but it is not at present marketed on account of lack of transportation facilities. The low-grade sub-bituminous coal of Thurston, Lewis and Cowlitz counties crumbles when exposed to sun and air, and must be used within a short time after it is brought from the mine or it will crumble to pieces and fall through the grate. From several pages of analyses given in Bulletin 474, the following are selected to show the range in variation of the coals of the State. Figures in the second place of decimals are omitted.

County.	As Received.		Combustible.							
	Moisture.	Ash.	Vol.	F.C.	S.	H.	C.	N.	O.	B.T.U.
Clallam........	11.2	12.6	52.5	47.5	6.7	6.2	74.4	1.2	11.5	13,760
Cowlitz........	15.2	18.9	55.1	44.9	4.4*					
King..........	14.8	8.3	43.3	56.7	0.5	5.7	76.0	1.7	16.1	13,300
"	5.5	21.0	43.9	56.1	0.9	6.0	80.9	2.2	9.9	14,720
"	8.2	10.7	33.5	66.5	0.6	5.3	85.9	2.3	5.9	15,340
Kittitas........	8.5	12.1	44.0	56.0	0.6	5.8	79.0	1.9	12.8	14,300
"	3.3	12.2	40.3	59.7	0.4	6.2	83.6	2.0	7.8	15,280
Lewis..........	9.8	69.8†	33.4	66.6	1.2	.....	.....	.....	....	9,790
"..........	29.1	7.7	54.9	45.1	2.8	5.5	71.7	1.2	18.9	12,580
"	4.2	34.1	17.0	83.0	0.8	4.2	86.9	1.4	6.7	14,400
"	2.7	10.7	8.2	91.8	0.7	3.7	91.4	1.5	2.7	15,410
Pierce.........	6.7	18.5	43.8	56.2	0.6	5.7	78.6	2.1	13.0	14,210
"	1.9	10.3	26.5	73.5	0.6	5.5	87.9	2.4	3.6	15,630
Thurston.......	25.1	8.7	48.7	51.3	1.2	5.4	71.3	1.4	20.7	12,320
"	22.4	11.0	50.5	49.5	3.6	5.3	73.4	1.1	16.6	13,170

* In coal as received. † This is a carbonaceous shale, not a merchantable coal.

Alaska.—The following information is condensed from a report on the mining and mineral wealth of Alaska, by A. H. Brooks, published by the U. S. Geological Survey in 1909:

The coal fields can be grouped into three general provinces—(1) the Pacific slope, (2) the central region, and (3) the northern region. In the first are included the lignitic and sub-bituminous coals of southeastern Alaska, Cook Inlet, Susitna basin, and the Alaska Peninsula, as well as the high-grade fuels of the Controller Bay and Matanuska regions. The central province includes some bituminous and sub-bituminous coals on the lower Yukon, besides more extensive fields of lignitic coal in the upper Yukon basin, near the coast line of Bering Sea, and elsewhere. The northern region includes the bituminous and sub-bituminous coals of the Cape Lisburne region, as well as lignitic and sub-bituminous coals in the Colville basin.

In the one-fifth of Alaska which has been geologically surveyed, the areas of coal-bearing rocks cover 12,644 square miles, containing 1238 square miles of known coal areas, viz., anthracite, 30.6; semi-bituminous, 54.7; bituminous, 47.2; lignite 861 square miles.

The Matanuska coal field lies about 25 miles from tide water at Knik Arm, a northerly embayment of Cook Inlet. The known com-

ANALYSES OF ALASKA COAL.

[Compiled from U. S. Geological Survey reports.]

District and Kind of Coal.	Moisture	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
ANTHRACITE.					
Bering River, average of 7 analyses	7.88	6.15	78.23	7.74	1.30
Matanuska River, 1 sample	2.55	7.08	84.32	6.05	.57
SEMI-BITUMINOUS.					
Bering River, coking, average of 11 analyses	4.76	13.27	74.84	7.12	1.51
Matanuska R., coking, average of 16 analyses	2.71	20.23	65.39	11.60	.57
BITUMINOUS.					
Lower Yukon, average of 11 analyses	4.68	31.14	56.62	7.56	.48
SUB-BITUMINOUS.					
Matanuska River, average of 4 analyses	6.56	35.43	49.44	8.57	.37
Alaska Peninsula, average of 5 analyses	2.34	38.68	49.75	9.22	1.07
Cape Lisburne, average of 11 analyses	9.35	38.01	47.19	5.45	.35
LIGNITE.					
Port Graham, 1 sample	16.87	37.48	39.12	6.53	.39
Southeastern Alaska, average of 5 samples	1.97	37.84	35.18	24.23	.57
Colville River, 1 sample	11.50	30.33	30.27	27.90	.50
Upper Yukon, Canadian, aver. of 13 analyses	13.08	39.88	39.28	7.72	1.26
Seward Peninsula, 1 sample	24.92	38.15	33.58	3.35	.68
Kachemak Bay, average of 6 analyses	19.85	40.48	30.99	8.68	.35
Unga Island, average of 2 analyses	10.92	53.36	28.25	7.47	1.36
Tyonek, average of 4 analyses	8.35	54.20	30.92	6.53	.38
Chistochina River, 1 sample	15.91	60.35	19.46	4.28	

mercially valuable coals of the field vary from sub-bituminous to semi-bituminous, with some anthracite. The beds vary from 5 to 36 feet in thickness, and the total area known to be underlain by coal is 46½ square miles. The total area of what may prove to be coal-bearing rocks is approximately 900 square miles. Up to the present time there has been no means of transporting this coal to market, so that no mining has been done, but many beds have been opened in prospecting. [A railroad is about to be built to this field by the Government. 1915.]

Lignites and Lignitic Coals of the Western States.*

Lignite is the next stage above peat in the formation of coal. It varies greatly both in appearance and in chemical composition. Its color ranges from light yellow to deep brown or black. The lignites belong to a later geologic period than the Carboniferous. They occur principally in Cretaceous and Tertiary formations. The beds, which are often of great thickness, present the same general characteristics as those of the true coals. Many instances occur in which portions of beds of lignite have changed to bituminous and even to anthracite. The lignites of Western America resemble the "brown coals" of Europe in holding a large amount of water, the percentage in most of them being from 12 to 15, though some have as low as 4 and others as high as 20 per cent. The percentage of ash is usually low, from 2 to 9 per cent, while the sulphur is generally below 1 per cent. The following analyses are given by Dr. R. W. Raymond in Trans. A. I. M. E., vol. ii., 1873:

	C.	H.	N.	O.	S.	Moisture.	Ash.
Monte Diablo, Cal	59.72	5.08	1.01	15.69	3.92	8.94	5.64
Weber Cañon, Utah.....	64.84	4.34	1.29	15.52	1.60	9.41	3.00
Echo Cañon, Utah......	69.84	3.90	1.93	10.99	0.77	9.17	3.40
Carbon Station, Wyo. ..	64.99	3.76	1.74	15.20	1.07	11.56	1.68
" " " ...	69.14	4.36	1.25	9.54	1.03	8.06	6.62
Coos Bay, Oregon......	56.24	3.38	0.42	21.82	0.81	13.28	4.05
Alaska................	55.79	3.26	0.61	19.01	0.63	16.52	4.18
"	67.67	4.66	1.58	12.80	0.92	3.08	9.28
Cañon City, Colo.......	67.58	7.42	.....	13.42	0.63	5.18	5.77
Baker Co., Ore.........	60.72	4.30	.....	14.42	2.08	14.68	3.80

Texas.—According to Bulletin No. 189 of the University of Texas the lignite fields probably extend over 60,000 square miles

* Including the sub-bituminous coals of the classification of the U. S. Geol. Survey.

and contain a supply in excess of 30,000,000,000 tons. Every known variety of lignite is found from a material carrying but a few per cent of fixed carbon to nearly 45 per cent, and with from 30 per cent volatile matter to more than 76 per cent. Physically the lignites range from what is but little more than carbonized wood to a material almost like bituminous coal. In thickness, the beds run to 15 feet or more, and they are found from the surface to depths of 400 to 600 feet. In a general way lignite is found in all that part of Texas lying west of long. 97° W. and north of lat. 31° N., but there are important areas outside of these boundaries. The following analyses show the extreme range of composition and the average of fifteen mine samples:

	Moisture.	Vol.	F. C.	Ash.	S.	C.	H.	O.	N.	B.T.U. per lb. as mined.	B.T.U. per lb. Combustible.
Milam Co.	29.1	29.0	24.5	17.6	3.3	38.7	2.7	7.3	1.4	7439	13,900
Hopkins Co. ...	33.9	45.9	3.4	16.8	0.7	34.1	2.3	11.1	1.1	6474	13,130
Av. of 15	33.0	40.4	17.2	9.0	1.1	40.1	3.0	12.3	1.2	7614	13,310

Another series of 23 samples received from mining companies gave moisture 7.3 to 37.3, av. 25.2; volatile matter 20.3 to 45.6, av. 37.6; fixed carbon 21.1 to 38.9, av. 28.5; ash 4.8 to 6.1, av. 8.8. B. T. U. per lb. as received 6291 to 10,411, av. 7661 B. T. U. per lb.

In his report on brown coal and lignite (Geol. Survey of Texas, 1892) Mr. E. T. Dumble gives the ultimate analysis of 22 brown coals, dried at 221° F. The average figures are, C, 60.98; H, 4.01; O, 22.16; N, 1.48; ash, 11.01. Water in the freshly mined coal 8.55 to 18.25, av. 13.67.

Arizona.—Several beds of lignitic coal of extremely variable composition have been found in the Territory. Two analyses of coals from Deer Creek, Ariz., taken from locations 8 miles apart are given below. The first is a semi-bituminous coal; the second, a lignite:

	I.	II.
Volatile combustible matter and water.......	14.5	47.6
Fixed carbon............................	61.0	44.0
Ash....................................	24.5	8.4

Although Arizona has not produced any coal on a commercial scale, there are fields of much promise which may be profitably exploited when transportation is afforded and when population and manufactures have reached a point which will provide a market for the output.—*Mineral Resources,* 1910.

Idaho.—There are several areas in Idaho in which lignite beds are found, but little mining has been done. The production, which was 6508 tons in 1907, declined to 4448 tons in 1910.

North Dakota.—The coal of North Dakota is a lignite of inferior quality and does not compare favorably with that brought from other localities. The output is restricted to local markets. It has been found well adapted for brick-burning on account of its smokeless quality.

Nevada.—A bed of coal, 5 to 6 feet thick, 20 miles east of Eureka, is mined for local consumption.

California.—The Mt. Diablo coal-field contains several beds, which vary greatly in thickness. The coal is of rather inferior quality. Coal has been found in many portions of the State, but the beds are mostly small in extent and the quality poor. Nearly all of the coal of California is lignite, that from Monterey County alone being classed as bituminous. San Francisco is dependent for its coal supply chiefly on coals brought by water from other States and from foreign countries. An analysis of Mt. Diablo coal is as follows:

Moisture	14.69
Volatile matter	33.89
Fixed carbon	46.84
Ash	4.58

At various times, within the last ten years, efforts have been made to exploit the California fields, but they have not been successful.—"Mineral Resources," 1910.

Oregon.—The developments are confined to the coal-basin in Coos County, though other lignite discoveries have been reported. The field covers several hundred square miles of territory, stretching from the coast 15 or 20 miles inland. The coals are true lignites, very high in water and volatile matter.

OREGON LIGNITES.

	Moisture.	Vol. Mat.	Fixed Carbon.	Ash.	Sulphur.
Coos Bay	15.45	41.55	34.95	8.05	2.53
"	17.27	44.15	32.40	6.18	1.37
Yaquina Bay	13.03	46.20	32.60	7.10	1.07
John Day River....	4.55	40.00	48.19	7.26	.60
" "	6.54	34.45	52.41	5.95	.65

CHAPTER V.

TESTS OF THE HEATING VALUE OF AMERICAN AND FOREIGN COALS.

Johnson's Tests of American Coals.—The results of the tests of American coals made by Prof. Walter R. Johnson for the United States Navy Department in 1842 and 1843, the report of which was published in a government document covering 600 pages, are of little use in determining the relative value of American coals when burned under the conditions of modern practice. The boiler used by Johnson was of the two-flue type, set only 9 to 10 inches from the grate-bars, the furnace being entirely unsuited for bituminous coal. Some of the anthracites were burned with an excessive air-supply, causing them to give results much below those that may be obtained under favorable conditions.

Scheurer-Kestner's Tests of European Coals.—A series of tests of European coals was made by Scheurer-Kestner and Meunier-Dollfus in 1868, and the results were reported in the *Bulletin de la Société Industrielle de Mulhouse*. An excellent study of these tests, with others, is that by M. L. Gruner in his papers on "The Classification and Heating Power of Coals," translated from the French by R. P. Rothwell, and published in the *Engineering and Mining Journal*, July 18th, 1874, *et seq.**

Mahler's Tests of European Coals.—MM. Scheurer-Kestner and Meunier-Dollfus found that the heating power as determined by the Favre and Silbermann calorimeter was notably higher than that calculated from the analysis by means of the Dulong formula. More recently numerous determinations, by different American chemists, of the heating values of various American coals, by means of the Thomp-

* Considerable space was given in the first edition of this book to the discussion of Johnson's and Scheurer-Kestner's tests. They are now considered unimportant, in view of more recent tests. A critical review of these tests was published by the author in *The Engineering and Mining Journal* in October, 1891.

son calorimeter or its modifications, showed, apparently, that the heating values of these coals were much less than those calculated from the analyses. The contradictory results of all these researches must now be set aside in view of the work of Mahler, in France, published in 1892, supplemented by the more recent work of Lord and Haas in this country and by that of Bunte in Germany, all of whom agree in showing that the calorimetric values and those calculated by the Dulong formula from the ultimate analysis are nearly identical, except in the case of cannel-coal, lignite, turf, and wood, which by Mahler's tests show a calorimetric value ranging from 2 to 12 per cent higher than that calculated from the analysis.

Mahler's research was made under the auspices of the Société d'Encouragement pour l'Industrie Nationale, with its financial assistance to the extent of 3000 francs, and his report is published as a pamphlet extract from the *Bulletin* of the Société, of 1892, occupying 73 pages quarto, with two large plates. It is entitled "Contribution à l'Etude des Combustibles; Détermination Industrielle de leur Puissance Calorifique, par P. Mahler, Ingénieur Civil des Mines," etc.

The calorimeter used by Mahler was a modified form of the "calorimetric bomb" of MM. Berthelot and Vielle, described in the *Annales de Physique et de Chimie* in 1881 and 1885. The bomb, with its auxiliary apparatus, is shown in the cut, Fig. 7, on page 145. It is described in detail by the report, and the description of a similar bomb, used by Professors Slosson and Colburn in their investigations of Wyoming coals, with the method of operating it, is given below.

Mahler's results are shown in condensed form in the table on the opposite page.

Mahler's formula gives the same result as his modification of Dulong's when $O + N = 3.29\%$, and higher results when $O + N$ is greater than 3.29%, but the difference is small, less than 1%, until $O + N$ becomes greater than 10%. The average results for the several classes of coals calculated by the Mahler formula are greater or less than the calorimetric results, as follows: Anthracite and anthracitic, + 19; fat and semi-fat,—34; fat gas-coals, + 117; flaming coals, lignitic, + 42; average of these four classes, + 26, as compared with —18, the average difference between the results calculated by the modified Dulong formula and the calorimetric result, as shown in the table. For the lignites, turf, and wood, Mahler's formula gives much smaller differences than Dulong's, viz.: + 102, + 6, + 194, —294, + 119, + 134, + 64, as compared with —157, —299, —138, — 734,

HEATING POWER OF COALS. (P. MAHLER.)

	Kind of Coal.	Coal Dry and Free from Ash.						
		Per cent Fixed Carbon.	Composition.			Heating power Calories.		
			C.	H.	O + N.	Actual.	By Dulong's* Formula.	Difference.
	Anthracite and Anthracitic.							
1	Pennsylvania	97.00	95.37	2.20	2.43	8256	8462	+ 206
2	De la Mure (Grand Couche)	97.25	95.24	1.50	3.26	8216	8173	− 43
3	Hay-Duong (Tonkin)	96.83	92.86	2.16	4.99	8121	8130	+ 9
4	Kebao	94.80	93.46	3.07	3.48	8532	8528	− 4
5	Commentry	96.81	91.49	3.12	5.39	8456	8333	− 123
6	Blanzy, Puits Ste.-Barbe	94.00	90.00	3.17	6.83	8203	8169	− 34
7	Grande-Combe, Puits Petassas	93.29	91.46	3.95	4.59	8540	8653	+ 113
8	Creusot	89.56	92.39	3.78	3.83	8687	8704	+ 17
	Average	.....	.....	....	.....	....	....	+ 18
	Fat and Semi-fat (Demi-grasse).							
9	Demi-grasse, d'Anzin, Fosse St. Marc	85.92	91.26	4.27	4.48	8656	8751	+ 95
10	" Grande Combe	86.62	91.19	4.46	4.35	8756	8817	+ 61
11	" Roche-la-Molière	86.00	90.11	4.38	5.51	8767	8651	− 116
12	" Aniche	88.07	90.10	4.40	5.49	8834	8659	− 175
13	Grasse, Anzin, great vein	78.49	89.20	4.67	6.14	8574	8651	+ 77
14	" Ronchamp	76.77	88.89	4.84	6.27	8797	8678	− 119
15	" Lens	80.50	90.03	4.80	5.17	8839	8805	− 34
16	" Carmaux	78.25	87.84	4.87	7.30	8639	8559	− 80
17	" Roche-la-Moliere	77.15	89.53	4.84	5.63	8867	8757	− 110
18	" Saint Etienne	79.16	89.23	5.03	5.74	8857	8796	− 61
19	" Mines de Portes (Gard)	80.71	86.52	4.84	8.64	8667	8382	− 285
	Average	.....	.....	....	....	....	....	− 66
	Fat Gas-coals.							
20	Bethune	69.59	87.03	5.37	7.60	8668	8654	− 14
21	Lens	69.20	87.26	5.44	7.30	8749	8705	− 44
22	Firminy	67.98	85.39	5.58	9.13	8573	8524	− 49
23	Montrambert	65.73	84.52	5.54	9.94	8598	8407	− 191
24	Commentry	60.04	85.66	5.60	8.73	8408	8573	+ 165
25	Wigan, Lancashire	68.36	88.57	5.72	5.72	8768	8979	+ 211
26	Cannel-coal, Niddrie	47.00	83.79	6.57	9.63	8431	8717	+ 286
	Average	.....	.....	....	.....	....	....	+ 52
	Flaming Coals, Lignitic.							
27	Montoie	62.93	88.95	5.64	10.42	8570	8371	− 199
28	Blanzy (Puits Ste.-Marie)	68.05	84.26	5.27	10.46	8350	8271	− 79
29	Decazeville (Bourran)	64.20	83.17	5.68	11.14	8270	8294	+ 24
30	Blanzy (Puits Ste.-Eugénie	60.61	81.54	5.64	12.83	8083	8072	− 11
31	Decazeville (Tramout)	58.77	78.72	5.67	15.61	7837	7735	− 102
	Average	.....	.....	....	.....	...	....	− 74
	Average of above four classes	....	.....	....	.....	....	....	− 18
	Lignites.							
32	Terre de Feu	47.23	71.01	5.94	23.05	7039	6882	− 157
33	Trifail (Styria)	49.66	69.24	5.06	25.71	6616	6317	− 299
34	Vaurigard	50.05	66.36	5.01	28.63	6076	5938	− 138
35	**Turf from Bohemia**	31.07	57.21	5.96	36.82	5903	5169	− 734
	Wood.							
36	Partially dry, Sapin de Norvège	.....	51.08	6.02	42.90	4828	4428	− 400
37	Bois de Chêne de Lorraine	.....	50.44	5.88	43.69	4689	4293	− 396
38	Cellulose, $C_{12}H_{10}O_{10}$	...	44.44	6.17	49.39	4200	3617	− 583

* Dulong's formula, slightly modified by Mahler, is: $Q = \frac{1}{100}\left[8140C + 34{,}500\left(H - \frac{(O+N)-1}{8}\right)\right]$.

It may be put under the form $Q = \frac{1}{100}\ [8140C + 34{,}500H - 4312(O + N - 1)]$.

Mahler's own formula is $Q = \frac{1}{100}\ [8140C + 34{,}500H - 3000(O + N)]$.

—400, —396, —583, the figures in the table. For all ordinary coals, therefore, Dulong's formula may be considered the more accurate of the two, giving an average difference of only 18 calories* in over 8000.

DESCRIPTION OF MAHLER'S BOMB CALORIMETER.†

The essential conditions for the determination of heat of combustion are that the product be completely burned, that the heat pass entirely into the water of the calorimeter vessel, and that the combustion be as quick as possible. These conditions are best attained by the process devised by Berthelot, according to which the combustion takes place in a closed steel vessel (the so-called bomb) filled with oxygen under twenty to twenty-five atmospheres pressure and almost entirely immersed in the water of the calorimeter. Under these circumstances a hydrocarbon burns completely to carbon dioxide and water in a few seconds, none of the products of combustion can escape and the heat passes into the surrounding water in the course of two or three minutes. The high price of Berthelot's calorimeter, about $1500, has prevented it from coming into common use. In June, 1892, an account was published of a modification of Berthelot's apparatus invented by M. Mahler in which the expensive platinum lining of the bomb was replaced by a thin coating of enamel without impairing the efficiency of the instrument. A calorimeter of this kind was procured by the University of Wyoming in July, 1894, for the study of the coal and petroleum of the State and for use in food investigations in the Agricultural Experiment Station.

The bomb (*B* in cut) of our apparatus is 15 cm. high and 10 cm. in diameter, with an average thickness of 8 mm. It is Martin-Siemens soft-forged steel of a resistance of 50 kilogs. per sq. mm. of section (about 70,000 lbs. per sq. in.), and 20% elongation. It is nickel-plated on the outside and coated on the inside with a thin white enamel to prevent corrosion by the oxygen and the acids which are among the products of combustion. The capacity of the bomb is 580 cc. A platinum tray (*C*), of 30 mm. in diameter and 5 mm. in

* A calorie is the amount of heat required to raise 1 kilogram of water 1° centigrade, =3.968 B.T.U. When used as a measure of the heating value of a fuel it is the number of units of weight of water which may be heated 1° C. by the combustion of 1 unit of weight of the fuel. The unit of weight may be either a gram, a kilogram or a pound. When thus used a calorie is equivalent to 1.8 British thermal units.

† From an article on "The Heating Power of Wyoming Coal and Oil," by Professors E. E. Slosson and L. C. Colburn, published in a special Bulletin of the University of Wyoming, Laramie, Wyo., January, 1895. Another description will be found in Mahler's paper on "The Calorific Power of Combustibles" (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1892), and in Poole's 'Calorific Power of Fuels' (John Wiley & Sons, New York, 1898).

depth, is suspended from the cover by a rod of platinum. A similar rod passing through the cover, but insulated from it, reaches nearly to the tray and serves as the other electrode. The cover is screwed on over the top of the bomb and a hermetical joint secured by a ring of lead. The oxygen is passed in through the stem of the needle-valve, which is screwed down when the bomb is filled. The bomb is set in a support which touches the bottom of the calorimeter vessel on three points. The calorimeter vessel is a pail of thin brass, 23 cm. high and

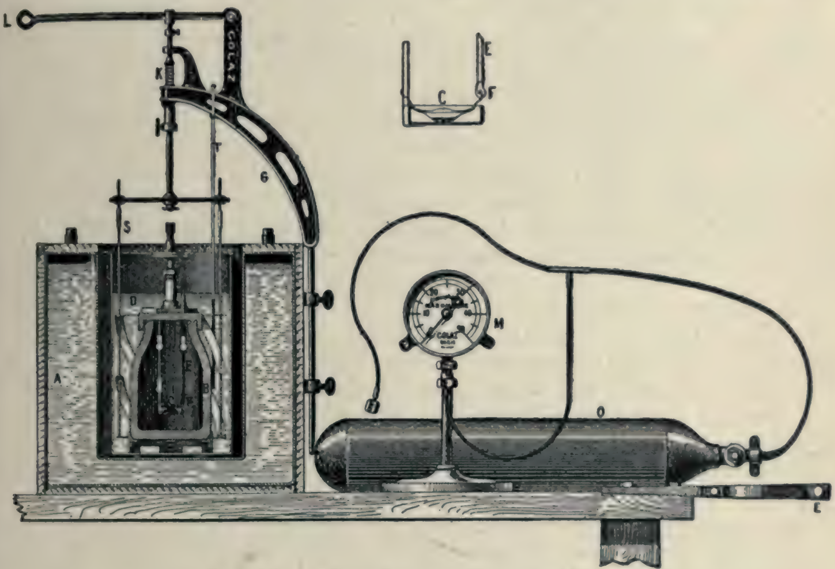

FIG. 7.—MAHLER'S BOMB CALORIMETER.

A, water-jacket; *B*, bomb of enameled steel; *C*, platinum tray; *D*, calorimeter-vessel; *E*, electrode; *F*, iron wire for ignition; *G*, support for stirring-apparatus; *K*, stirring-mechanism; *L*, lever for stirring; *M*, manometer; *O*, cylinder of oxygen; *S*, stirring-apparatus; *T*, thermometer; *Z*, clamp.

14 cm. diameter. This rests on three points of a light wooden support, and is surrounded by a large double-walled vessel, covered with thick felt, containing water at the normal temperature of the room. An ingenious stirring mechanism enables one to keep the water of the calorimeter in thermal equilibrium with slight effort. The calorimeter is so well isolated from external influences that the water often does not vary in temperature .01° in fifteen minutes, although the air of the room may be quite variable.

Two thermometers were used, one reading between 8° and 18° C., and the other between 18° and 28°; each degree covering a space of $3\frac{1}{2}$ cm. They are graduated to $\frac{1}{50}$°, and were read to 0.01°, although with a glass they can be read to a much finer interval.

The oxygen used was made in the laboratory, purified by passing through a solution of caustic potash and three rolls of copper gauze, and kept in gas-bags; the slight correction indicated for Berthelot for the loss of heat through vaporization of water has not been applied.

THE PROCESS OF COMBUSTION.

One gram of the coal or oil is weighed into the tared platinum tray, which is then attached to the platinum rod in the calorimeter-bomb. A piece of iron wire of known weight is stretched across from the rod supporting the tray to the insulated support, and preferably touching the combustible or buried in it. The bomb is then placed in a lead-lined clamp, and the top tightly screwed on by means of a wrench. The needle-valve is opened and connected with the compression pump by a long slender copper tube. Oxygen is then forced into the bomb until the manometer reads 20 or 25 atmospheres. The needle-valve is closed and disconnected from the filling tube, and the bomb is immersed in the water of the calorimeter. The water should be 2° to 3° lower in temperature than the air of the room and the water in the jacket of the calorimeter, and a sufficient amount should be weighed out to cover the bomb nearly to the top of the insulated electrode. In our instrument 2309 grams of water was usually taken, as that gave with the water value of the apparatus (491 grams) a convenient factor for calculation. The stirring apparatus is kept in motion, and, as soon as the change in temperature becomes constant, readings of the thermometer are taken at intervals of one minute. At the end of the fifth minute the combustible is fired by passing an electric current through the iron wire, raising it to redness. We used a plunge battery of six bichromate cells for this purpose. One wire is connected to the insulated electrode, and the other is touched to some exposed part of the bomb. In about ten seconds the thermometer is observed to rise, rapidly at first, then more slowly, reaching a maximum usually on the second or third minute after firing. After the maximum it falls regularly and slowly if the proper temperature has been chosen for the water, and readings are again made at intervals of a minute for five minutes more. Then the bomb is taken out of the calorimeter, the needle-valve cautiously opened to allow the products of combustion and residual oxygen to escape; after which the bomb is opened and rinsed out with distilled water. The rinsings are titrated with a standard solution of potassium hydrate or sodium carbonate to determine the amount of nitric acid formed by the combustion; and, if the combustible contains sulphur, the solution is set aside for determination of sulphuric acid. The whole operation, including the weighing of the sample and pumping in the oxygen, can be completed in less than an hour if everything works well.

Multiplying the weight of water taken plus the water value of the apparatus by the corrected rise in temperature gives the heat of

combustion of one gram of the substance, subject to the corrections mentioned below.

CORRECTIONS.

1. *Correction for the Influence of the Temperature of the Environment.*—This is the largest and most important correction to be made, although on acount of the short interval during which the temperature rises—usually two minutes—it is smaller in this process than in any other.

As there is no way of measuring directly the amount of heat lost or gained by the calorimeter from the moment of firing to the moment when all the heat of combustion has been given up to the water surrounding the bomb, it is necessary to calculate this from the rate of change of temperature before firing and the rate of change when the temperature has come again to equilibrium. This correction is most accurately given by the application of the Regnauld-Pfaundler formula. If the preliminary period and the final period are each five minutes, with readings of the thermometer every minute, the correction according to this formula is:

$$[t_6 + t_7 + \ . \ . \ . \ t_{N-1} + \frac{t_5 + t_N}{2} - (N - 5)t_M]\frac{D - d}{T - t_M} + (N - 5)d,$$

where t indicates the temperature at the end of the minute designated by the subscript; t_5 is the instinct of firing; N is the number of the maximum reading; t_M is the average of the five readings before firing; T is the average of the readings of the final period; D is the average change in temperature during the final period, and d is the average change in temperature during the preliminary period.

As in practice the maximum temperature nearly always occurs on the seventh, the eighth, or the ninth minute, the formula can be reduced for these three cases to the following forms, which are easy to calculate:

When the maximum is the end of the seventh minute the correction for the loss or gain of heat during the minutes 5–6 and 6–7 is

$$\frac{1}{5}\left\{\frac{[(2t_6 + t_7) - (2t_0 + t_5)][(t_7 + t_5) - (t_0 + t_{12})]}{(t_{12} + t_7) - (t_0 + t_5)} + (t_0 - t_5)\right\}.$$

When the maximum is the eighth minute the loss or gain for the minutes 5–6, 6–7, 7–8 is

$$\frac{1}{5}\left\{\frac{[(2t_6 + 2t_7 + t_8) - (3t_0 + t_5)][(t_8 + t_5) - (t_{13} + t_0)]}{(t_{13} + t_8) - (t_0 + t_5)} + 3(t_0 - t_5)\right\}$$

When the maximum is the ninth minute the loss or gain for the minutes 5–6, 6–7, 7–8, 8–9 is

$$\frac{1}{5}\left\{\frac{[(2t_6+2t_7+2t_8+t_9)-(4t_0+t_5)][(t_9+t_5)-(t_{14}+t_0)]}{(t_{14}+t_9)-(t_0+t_5)}+4(t_0-t_5)\right\}.$$

This correction becomes a minimum when the temperature before firing is rising about three times as fast as it falls after the maximum.

As the period of combustion is so short, M. Mahler has given a method of correction based on Newton's law which gives results sufficiently exact for technical work. His rules are:

I. The law of decrease of temperature observed after the maximum represents the loss of heat before the maximum and for any given minute, on condition that the mean temperature of this minute does not differ more than one degree from the maximum temperature.

II. If the temperature of the given minute differs by more than one degree but less than two degrees from that of the maximum, the number that represents the law of decrease at the moment of the maximum less 0.005 will give the desired correction.

A comparison of the two methods in some twenty cases showed an average difference of 0.0013, which on one gram naphthalene would amount to about three calories, or 0.03 per cent; a difference within the limit of error in technical work.

2. *Correction for Formation of Nitric Acid.*—About fifty milligrams of nitric acid are formed from the nitrogen of the air by the combustion, and it is necessary to ascertain the amount of this and subtract the heat of formation, 227 cal. per gram, from the heat of combustion of the substance under examination. This is estimated by titration with a standard alkali solution containing 3.706 grams of sodium carbonate, Na_2CO_3. One cubic centimeter of this solution is equal to .0044 gram nitric acid, of which the heat of formation is one calorie, so the number of cubic centimeters required to titrate the washings of the bomb can be written at once as calories. Methyl orange is used as an indicator.

3. *Correction for the Combustion of the Iron Wire.*—The combustion of the small piece of iron wire used to ignite the combustible adds to the apparent rise in temperature, and correction must be made by taking a known weight of wire and subtracting its heat of combustion. A No. 32 to 36, Brown and Sharpe gauge, is suitable, and it is preferable to use the copper-plated wire, as the plain wire easily becomes oxidized on the surface. Of No. 36 wire one meter weighs .3160 gram; of this in our experiments we used a length of 4.8 centimeters, giving a heat of combustion of 25 calories.

The heat of combustion of iron under these circumstances is stated to be 1650 cal. per gram.* This is on the assumption that all the iron is burned to Fe_3O_4. That this is not correct is shown by the

* Berthelot: Traité Pratique de Calorimetrie Chimique, p. 139.

following analysis of the iron oxide resulting from some twenty combustions each: No. 1, 71.59 per cent iron in oxide; No. 2, 75.81 per cent iron in oxide. The first would correspond to 74.7 per cent Fe_3O_4 and 25.3 per cent Fe_2O_3, while the second might be composed of 86.8 per cent Fe_3O_4 and 13.2 per cent unburned iron. Other mixtures of iron and its oxides would of course give the same analytical results. The heat of combustion of ferric oxide is not exactly known, but it is certainly less than that of Fe_3O_4. It appears from this that the character of the oxides formed is variable and the ordinary correction consequently inaccurate by several calories. The error is not, however, as great as the analysis would seem to indicate, for it was only the larger particles such as could be easily picked off that were taken for analysis.

4. *Correction for Sulphur.*—The presence of sulphur in the combustible necessitates another correction, for the free sulphuric acid formed by the combustion of sulphur compounds will be titrated as nitric although its heat of combustion is different and the heat of the burning sulphur is a legitimate part of the heat of combustion of the fuel. The sulphuric acid must therefore be determined in the rinsings of the bomb after the titration for free acid, and the heat of formation of its equivalent in nitric acid subtracted from the number obtained by titration. The weight of barium sulphate multiplied by 100 gives directly the number of calories to be subtracted.

Sulphur, however, exists in coal in three forms: organic sulphur compounds, pyrites, and sulphates, chiefly gypsum. Of these the third at least would not be converted into free acid by the combustion, and the ordinary correction would be too great. The point is of especial importance in dealing with Wyoming coals, for, although the percentage of sulphur is generally small, yet it is more often in the form of gypsum than pyrites. Nevertheless, as to find the original state of the sulphur would require two analyses, the whole is regarded as forming sulphuric acid, and the equivalent, usually amounting to about 5 cal., has been subtracted in all cases.

DETERMINATION OF WATER VALUE OF THE APPARATUS.

The heat produced by combustion is absorbed not only by the water in the calorimeter, but also by the calorimeter vessel, the bomb, the stirring apparatus and thermometer in contact with it. But the amount of heat absorbed by them depends on their weight and material. It is therefore necessary to find the water value of the apparatus, that is, what weight of water would absorb the same amount of heat for the same rise in temperature. This is done by multiplying the weight of the different parts of the apparatus by the specific heat of the material of which they are composed.* In this case the calculation was as follows:

* The weight of the enamel on the bomb was not known. The water value of the apparatus as calculated is therefore too low.

Calorimeter vessel 445 g., stirring apparatus 143 g., 588 g. brass × .093	54.69
Bomb, 3920 g. steel × .1097	430.03
22.36 g. platinum × .0324	.72
8 g. lead × .031	.25
Thermometer, bulb 2.72 g., tube 33.56 g., ¼ immersed, 8.61 g. glass × .184	1.58
35.36 g. mercury × .033	1.17
Oxygen, (20 atmospheres pressure) 16.7 × 155 *	2.59
Water value	491.03

Another method of determining the water value of a calorimeter is to burn in it certain compounds whose heat of combustion is accurately known. This has the advantage that the water value of the whole apparatus is determined directly and under the same conditions as in an ordinary combustion, but it has the disadvantage that the heat of combustion of no compound is exactly known. In determining the water value of our calorimeter we made twelve combustions with resublimed naphthalene, of which the heat of combustion as determined by Berthelot and his assistants is 9692 calories. The average of the twelve combustions gave 491.4 grams as the water value of the calorimeter. One combustion with granulated sugar, using 2 gm. and taking the heat of combustion as 3961.7 cal. per gram, gave 491 g. as the value. As all these are in satisfactory agreement, the number 491 has been adopted as the water value. A difference of one gram in water value makes a difference of about .03 per cent in the final result.

An Example.—The method of calculating the heat of combustion may be made more clear by giving in detail an example in which the corrections are ususally large.

Coal No. 33. L. R. Meyer, Carbon. November 30, 1894.
1 gram coal. .0250 g. wire. 2300 g. water in calorimeter.

Preliminary Period.	Combustion Period.	Final Period.
0—11.47° C.	5—11.48° C.	9—13.64° C.
1—11.47	5½—12.50	10—13.63
3—11.48	6—13.34	11—13.62
4—11.48	7—13.63	12—13.62
5—11.48 Fired.	8—13.64	13—13.62
	9—13.64	14—13.61

Nitric acid = 9.0 cc. Sodium carbonate solution = 9 cal. Weight $BaSO_4$, .0472.

* Specific heat at constant volume.

From the 9th to the 14th reading .03° heat was lost, or .006° per minute. Then for the three and a half minutes, 5½–6, 6–7, 7–8, 8–9, the total loss = .021°. The temperature rose .01° during the preliminary period, or .002° per minute. The correction for the half-minute 5–5½ is therefore .001. The total rise in temperature is from 11.48° to 13.64°, or 2.16°; adding to this the correction .02° gives 2.18° for the true rise due to combustion. The water value of the apparatus, 491 g., added to the weight of water used, 2300 g., gives 2791 g., which multiplied by 2.18 gives 6084.4 calories. The weight of the barium sulphate with the decimal point moved two places to the right gives 4.7 to be subtracted from 9.0 cal., leaving 4.3 cal. The weight of the wire, .0250 g., multiplied by 1650 gives 41.2 cal. The sum of the corrections for formation of iron oxide and nitric acid, 45.5, subtracted from 6084.4 gives 6039 calories for the true heat of the combustion of one gram of the coal. The use of Regnault's formula in this case would make the rise of temperature 2.179° and the heat of combustion 6036 cal.

NOTES ON CALORIMETRY.

The use of a cylinder of oxygen under great pressure, such as is now in the market, dispenses with a compression-pump, and shortens the time required for a combustion by one-half. It has the disadvantage that the quality of the oxygen is not as much under control as where it is made in the laboratory.

It is not necessary that the coal should be finely powdered, nor is there any difficulty in using fine samples. Of the samples used, one was in coarse fragments and some had been passed through a hundred-mesh sieve. In using very fine coal or freshly sublimed naphthalene, it is convenient to compress it into tablets with a "diamond mortar" such as is used in crushing minerals for analysis.

The cylinder of the compression pump must be kept cool by a water-jacket, or the oil will become ignited by the compressed oxygen and an explosion result.

The rapidity with which the heat is given up to the water of the calorimeter is shown by the following average of ten determinations:

Heat given off during the period	5 –5½	= 27.9	per cent.
" " " " " "	5½–6	= 50.3	" "
" " " " " "	6 –7	= 20.1	" "
" " " " " "	7 –8	= 1.7	" "
		100.0	

That is, 78.2 per cent of the total heat is absorbed by the water during the first minute and 98.3 per cent during the first two minutes.

Care must be taken to scrape off the iron oxide from the electrodes before attaching the new wire, as a very thin film will prevent ignition by the electric current.

A third method of standardizing the calorimeter is used by the chemists of the U. S. Geological Survey (Bull. 415, 1910, p. 242). We quote . . . third, by adding a definite amount of warm water at known temperature to a definite amount of water at some known lower temperature in the calorimeter and noting the resulting temperature. From these data the actual heat equivalent can be calculated. The determination by each method is duplicated until satisfactory averages are obtained and a mean of these averages insures a figure for the water equivalent of the apparatus which is very near the truth.

The thermometer readings are made through a telescope at some distance from the calorimeter, so as to avoid errors due to radiation of heat from the body of the operator.

Determinations of the heating value of coal are always made in duplicate and almost invariably agree to within 50 British thermal units, or about one-third of 1 per cent. The practice of reporting heat values to the decimal or even to the final whole number assumes an extreme accuracy which the determination does not warrant. It would be far better and would not affect values if the British thermal units were reported to the nearest ten.

The Parr Calorimeter. A calorimeter invented by Prof. S. W. Parr, which is often used in commercial work and is less expensive than the Mahler, is shown in Fig. 8.

The can *AA* for the water has a capacity of 2 liters. The insulating vessels *BB* and *CC* are of indurated fiber. A charge of coal and chemical is put in the cartridge *D*. Upon ignition, the heat generated is imparted to the water and the rise in temperature is indicated on the finely graduated thermometer *T*. The cartridge or bomb rests on the pivot *F* and is made to revolve, and by aid of the small turbine wings attached effects a complete circulation of the water and equalization of temperature.

The oxygen required for combustion is supplied by sodium peroxide. The reaction accompanying the combustion may be represented by the equation:

$$\underset{\text{Sod. perox.}}{56Na_2O_2}+\underset{\text{Coal}}{C_{25}H_{18}O_3}=\underset{\text{Sod. carb.}}{25Na_2CO_3}+\underset{\text{Sod. hydrate}}{18NaOH}+\underset{\text{Sod. oxide}}{22Na_2O}$$

With certain substances such as coke, anthracites, petroleums, etc., a more vigorously oxidizing medium is needed than exists in the sodium peroxide alone, such as a mixture of potassium chlorate and nitrate in the proportion of 1 to 4 and this mixture used in the ratio of 1 to 10 of the sodium peroxide.

Further extension of the use of the instrument to other types of coal and to petroleum has made it necessary to extend still further the oxidizing power of the chemicals employed beyond what is afforded by the chlorate mixture. In addition to this the use of the residue for determining the total carbon and sulphur has made it highly desirable in such additional chemicals to avoid the use of compounds containing carbons or sulphur. To meet these conditions, the so-called "boro-mixture" has been devised. For the addition the following mixture has also been used: Boric acid, 11 parts; potassium chlorate, 4 parts; magnesium powder, 1 part. The correction factor of the mixture is found by trial with a pure chemical of known heat value, such as naphthalene or by burning with a coal whose heat value is already accurately known.

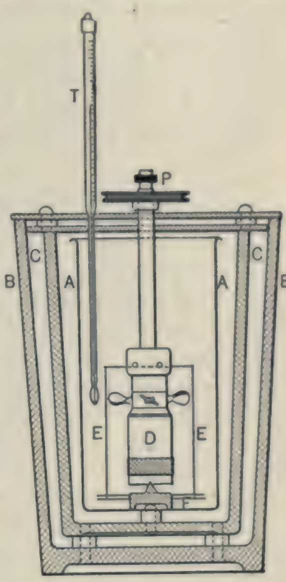

FIG. 8.—THE PARR CALORIMETER.

Lord and Haas's Tests of American Coals.—In 1897 Professors N. W. Lord and F. Haas, of the Ohio State University, Columbus, O., presented a paper to the American Institute of Mining Engineers (Trans., vol. xxvii. p. 259) giving the results of proximate and ultimate analyses and determinations of calorific value, by means of the Mahler calorimeter, of forty different samples of coal, selected from seven different mining regions. Prof. Lord also published a paper in *Engineering News* of February 16, 1899, giving the results of similar tests of five samples of coal from different parts of Jackson Co., Ohio. The figures obtained in both series of tests are given in the table on pages 156 and 157. The figures in the last two columns have been calculated by the author, to show the heating value and the per cent of fixed carbon of the combustible, which were not given in the original papers. The ultimate analyses as reported include the hydrogen and oxygen of the moisture together with that of the dry coal, and the figures for "average, dry coal," have been computed by the author in order to make the analyses comparable with analyses of other coals.

The extreme accuracy of these tests is shown by the close agreement of the results with those obtained by Mahler with foreign coals of similar composition, as well as by the correspondence of the calorimetric determinations with the heating value as calculated by the Dulong formula. The student is referred to the original paper for a detailed statement of the precautions taken to insure accurate work with the calorimeter.

The following is quoted from the paper:

"The probable error of a single calorimeter determination from the mean result of a large number was computed from all the results on 21 samples of coal, on each of which more than one determination was made. There were 50 separate results on the 21 samples. Computing the error by the ordinary formula gave plus or minus 20 units, or about 0.3 of 1 per cent as the probable error of one determination. These results were obtained by different observers and at considerable intervals of time, and include slight possible variations in the condition of the sample as to moisture and oxidation. Duplicate results obtained at the same time by the same observer frequently gave much closer checks.

"One gram of the coal was dried at 100° to 105° C. for one hour in a crucible, the loss being called moisture. After drying, the same portion was heated $3\frac{1}{2}$ minutes over a Bunsen burner, then $3\frac{1}{2}$ minutes over a blast-lamp, and the loss was called volatile combustible. The crucible was tightly covered and not allowed to cool during the change from burner to blast-lamp.

"The results of the work are given in the following tables, in which the coals of each seam are grouped together. In addition to the analytical and calorimetric data the following figures are tabulated:

"1. The calorimetric power, computed from Dulong's formula, in this form:

$$\text{Cal. power} = 8080C + 34{,}462\left(H - \tfrac{1}{8}O\right) + 2250S,$$

C, H, O, and S being the amounts of carbon, hydrogen, oxygen, and sulphur in one unit of the coal.

"2. The difference between this result and the bomb determination, expressed in percentages.

"On examining the accompanying table of results, the following points appear:

"In the first place, the remarkable coincidence between the heating powers, as calculated from Dulong's formula, and the experimental determinations. In the case of the averages of the different seams we find practical identity between the heating power as calculated from the formula based simply on the heat developed by the combustible elements, and the result of the calorimeter. This is so

much at variance with the claims of many writers that, were it not the result of so many determinations, it might pass as a mere accident. The maximum difference between the heat calculated from the elementary analysis and the heat developed in the bomb is 2 per cent of the total calculated heat, the minimum difference 0.1 per cent. The possible error of an ultimate analysis may be placed at 0.5 per cent on carbon and 0.2 per cent on hydrogen, especially with coals as high in ash and sulphur as are many of the samples included in our tests. This would lead to an error of about 108 units, or nearly 1.4 per cent on the calculated heat value. While, of course, the probable error of the ultimate analysis is less than this, it seams certainly possible that the differences between the observed and calculated heat values are within the limits of experiment.

"Attempts to derive a general law for all the coals examined were abandoned, and the question was taken up, how far the coal of a given deposit or seam can be regarded as of uniform quality, and its specific character determined. This has led to the interesting results given in the tables. Taking the coals of the same steam, we averaged the results of the calorimeter, and, reducing by the average ash and moisture, soon found that comparable results were obtained by regarding this value as a constant for the seam over the area examined."

"The results of our tests seem to indicate the interesting conclusion that the character of a coal-seam, as far as its fuel value is concerned, is a nearly constant quantity over considerable areas. The determination of the value for seams would be of great use, as the rapid proximate analysis, or, for that matter, merely the determination of ash and moisture, in low-sulphur coals, would be sufficient to grade coals of the same vein. Of course it is dangerous to argue from so few examples; but the proposition seems reasonable. At least, we hope that further work may confirm these conclusions.

Prof. Lord says concerning the Jackson Co., Ohio, coals:

"The failure of the last two samples to show close correspondence between the calculated values by Dulong's formula and the calorimetric results is contrary to our experience with other coals. These last two analyses are the average of duplicates, which do not agree very satisfactorily, and therefore the results are open to question, as I fear some carbon may have escaped combustion. The other analyses are the averages of very closely agreeing duplicates. If the conclusion as to the comparative constancy of the heating value of the combustible in any given seam is correct, then the determination of the heating power of any particular sample from the seam becomes a simple matter, if the ash, sulphur, and moisture in the sample be known, and the seam constant for the kind of fuel be known."

In an article on "The Heating Value of Coal," published by the author in Vol. 1 of "Mineral Industry," 1892, p. 97, Mahler's tests

TABLE OF RESULTS. LORD AND HAAS'S TESTS.

Location of Mine.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Moisture.	Volatile Combustible.	Fixed Carbon.	Calorimeter Result.	Calorific Power Calculated from Ultimate.	Difference. Per cent.	Coal Dry and Free from Ash.	
													Fixed Carbon.	Calorimeter Value.
POCAHONTAS COAL (SEMI-BITUMINOUS).														
Run of mine	83.75	4.22	3.36	.85	.57	7.25	.80	18.30	73.65	8062	8089	− .3	80.10	8768
" "	....	..	.....	...	.60	8.60	.75	17.05	73.60	7915	.	... .	81.19	8731
" "	85.46	4.25	3.24	.85	.57	5.63	.63	18.62	75.12	8185	8246	− .6	80.14	8732
" "	....	...	.....	....	.63	6.99	.61	17.92	74.48	8080	....	.....	80.61	8745
" "	85.40	4.39	3.94	.85	.62	4.80	.85	18.60	75.75	8281	8258	+ .3	80.29	8777
Average	.....	....	.....	...	.60	6.65	.73	18.10	74.52	8105	..	.....	80.48	8751
Average 1–3–5	84.87	4.29	3.51	.85	.59	5.89	.76	18.51	74.84	8176	8198	....	80.18	8759
" " Dry Coal.	85.52	4.24	2.85	.86	.59	5.94								
THACKER COAL, WEST VIRGINIA.														
Run of mine	78.90	5.14	6.88	1.42	1.16	6 50	1.40	35.00	57.10	7768	7876	−1.3	62.00	8434
" " 2d lot	.....	.	....	....	1.18	7.50	1.60	34.75	56.15	7738	..	... .	61.77	8513
Nut Coal	... .		. ..	..	1.81	7.30	1.18	36.07	55.45	7711	..	... .	60.59	8425
" " 2d lot	78.40	5.19	7.56	1.40	1.40	6.05	1.35	36.35	56.25	7867	7831	+ .4	60.75	8496
Average	.....	...	. . .	....	1.39	6.84	1.38	35.54	56.24	7771	....	....	61.28	8467
Average 11–14	78.65	5.17	7.22	1.41	1.28	6.27	1.38	35.68	56.67	7817	7853	.....	61.38	8465
" " Dry Coal.	79.75	5.09	6.07	1.43	1.30	6.36								
PITTSBURGH COAL, ALLEGHENY CO., PENNSYLVANIA.														
Carnegie	77.20	5.26	8.51	1.68	1.42	5.98	1.45	36.42	56.20	7691	7717	− .3	60.68	8304
Turtle Creek	76.56	5.22	7.00	1.67	1.60	7.95	1.08	34.38	56.59	7680	7719	−1.2	62.14	8378
Carnegie	76.57	5.13	8.82	1.64	1.76	6.08	1.07	37.79	55.06	7765	7614	+2.0	59.30	8352
"	73.50	5.19	8.08	1.44	2 54	9.25	1.08	37.67	52.00	7396	7436	− .5	57.99	8248
Creedmore	74.45	5.27	8.02	1.60	1.80	8.86	1.09	38.91	51.14	7496	7528	− .4	56.79	8324
N. Mansfield	73.91	5.15	8.89	1.23	1.77	9.05	2.10	36.20	52.65	7354	7404	− .7	59.26	8277
Turtle Creek	74.48	5.05	8.39	1.37	1.66	9.05	1.75	36.20	53.00	7394	7433	− .5	59.42	8299
Average	75.24	5.18	8.24	1.51	1.79	8.02	1.37	36.80	53.81	7582	7550	.....	59.39	8313
" Dry Coal.	76.30	5.10	7.12	1.53	1.82	8.13								
MIDDLE KITTANNING (DARLINGTON COAL), LAWRENCE CO., PENNSYLVANIA.														
Hoytdale	77 83	5 22	9.38	1.65	1.57	4.35	1.60	36.40	57.65	7785	7719	+ .9	61.30	8278
Beaver Creek	74.60	5.06	8.23	1.40	1.96	8.75	1.50	34.33	55.42	7360	7460	−1.3	61.75	8201
Wampum	77 93	5.17	7.95	1.65	2.35	4.95	0.75	38.53	55.77	7825	7787	+ .5	59.14	8256
Near Wampum	76.81	5.22	8.52	1.62	1.18	6.65	0.70	36.80	55.85	7638	7663	− .3	60.28	8244
Hoytdale	72.78	4.93	10.57	1.34	1.68	8.70	2.70	35.10	53.50	7245	7173	+1.0	60.38	8177
Wampum	72.82	5 25	8.55	1.33	3.25	8.80	2.85	37.50	50.85	7304	7395	−1.2	57.56	8267
Clinton	73.57	5.14	10.14	1.24	1.86	8.05	2.55	35.60	53.80	7300	7320	− .3	60.18	8166
Average	75.19	5.14	9.05	1.46	1.98	7.18	1.81	36.32	54.69	7494	7502	.....	60.09	8226
" Dry Coal.	76.58	5.03	7.57	1.49	2.02	7.31								

TABLE OF RESULTS. LORD AND HAAS'S TESTS.—*Continued.*

Location of Mine.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Moisture.	Volatile Combustible.	Fixed Carbon.	Calorimeter Result.	Calorific Power Calculated from Ultimate.	Difference. Per cent.	Coal Dry and Free from Ash. Fixed Carbon	Coal Dry and Free from Ash. Calorimeter Value.
UPPER FREEPORT COAL, OHIO AND PENNSYLVANIA.														
East Palestine, O......	70.58	4.88	7.76	1.24	3.65	11.89	0.82	34.98	52.65	7109	7132	− .3	60.08	8113
" "	73.23	5.15	8.82	1.47	1.75	9.58	1.65	37.45	51.32	7330	7352	− .3	57.81	8257
Waterford, O..........	74.39	5.15	7.80	1.40	3.44	7.82	1.55	37.29	53 34	7459	7529	− .9	58.85	8230
Yellow Creek, O.......	73.15	4.98	7.41	1.40	3.89	9 17	1.28	38.72	50.88	7464	7393	+1.0	56.79	8330
Steubenville, O........	74.73	5.26	8.06	1.44	2.85	7.66	1.47	39.23	51.54	7504	7567	− .8	56.78	8267
Cambridge, O..........	70.61	5.19	10.33	1.44	3.01	9.42	2.43	37.79	50.36	7088	7116	− .4	57.15	8041
Steubenville, O.......	71.40	4.62	10.68	1.20	3.00	9.10	2.40	39.20	49.30	7113	6970	+2.0	55.71	8037
Salineville, O...........	72.62	5.13	9.92	1.23	3.00	8.10	2.80	36.30	52.80	7271	7276	− .1	59.26	8160
Palestine, O............	71.29	5.00	9.28	1.34	2.64	10.45	2.15	36.70	50.70	7277	7136	+2.0	58.01	8339
New Galilee, Pa........	73.57	5.20	8.94	1.35	2 24	8.70	2.30	36.70	52.30	7267	7401	−1.8	58.76	8165
Palestine, O.	73.64	5.06	9.47	1.24	2.34	8.25	2.45	36.60	52.70	7344	7340	+ .1	59.01	8224
Average	72.65	5.06	8.95	1.34	2.89	9.10	1.93	37.35	51.63	7293	7292	....	58.02	8197
" Dry Coal...	74.09	4.94	7.37	1.37	2.95	9.28								
MAHONING COAL.														
Salineville, O...	71.13	4 95	9.93	1.23	1.86	10.90	3.15	35.00	50.95	7032	7068	− .5	59.28	8182
Dry Coal.	73.44	4.75	7.36	1.27	1.92	11.26								
JACKSON CO., OHIO.														
Center.................	70.05	5.43	17.09	1.49	1.84	4.10	8.26	35.15	52.49	6854	6835	−0.3	59.89	7821
North..................	71.20	5.50	17.71	1.45	0.76	3.38	8.45	34.09	54.09	6937	6890	−0.7	61.35	7868
South..................	70.12	5.49	16.96	1.50	1.45	4.48	7.02	37.66	50.82	6956	6860	−1.3	57.42	7860
West...................	71.42	5.37	19.49	1.43	0 64	1.65	8.65	34.30	55.40	6981	6795	−2.7	61.76	7783
East	70.79	5.55	18.60	1.46	0.95	2.65	8.50	37.75	51.10	7069	6854	−3.1	57.51	7946
Average.......	70.72	5.47	17.97	1.47	1.13	3.25	8.17	35.79	52.78	6953	6847	.....	59.59	7856
" Dry Coal...	77.00	4.97	11.66	1.60	1.23	3.54								
MIDDLE KITTANNING (HOCKING VALLEY COAL), OHIO.														
Lump.................	69.42	5.35	16.27	1.46	1.67	5.83	6.72	37.13	50.32	6882	6790	+1.3	57.54	7870
" 2d sample.......	.....	...	.	....	1.63	10 10	6.45	36.60	46.85	6663	....	.....	56.14	7913
Run of mine...........	66.50	5.16	15.57	1.43	1.67	9.67	6.65	34.14	49.54	6496	6520	− .4	59.20	7762
" " 2d sample......	.....	.	.....	....	1.50	10.53	6.34	35.18	47.95	6482	....	.....	57.68	7797
Lump, 3d sample......	68.18	5.36	15.09	1.44	1.48	8.50	6.40	36.05	49.05	6610	6740	−1.9	57.64	7767
Average.............	.....	....	.....	....	1.58	8.93	6.51	35.82	48.74	6612	.. .	.....	58.12	7822
Average 6-8-10... ...	68.03	5.29	15.64	1.44	1.59	8.00	6.59	35.77	49.64	6663	6683	. ...	58.16	7800
" " Dry Coal.	72.84	4.88	10.47	1.54	1.70	8.57								

were reviewed, and a curve was drawn showing the relation of the heating value per pound of combustible to the percentage of fixed carbon in the combustible. In a discussion of the paper of Professors Lord and Haas, in 1897 (Trans. A. I. M. E., vol. xxvii, p. 946), the same curve was presented together with plottings of the results of Lord and Haas, the results of tests of 13 coals by C. W. Houghton, M. E., in 1896, with a Carpenter calorimeter, the figures of which are given below, and the average results of tests of coals from four counties in Wyoming (see table on p. 160). The curve and plottings are reproduced on page 159. It appears that all of Mahler's tests of coals containing between 60 and 97 per cent of fixed carbon in the combustible (one cannel-coal excepted) are enclosed in a narrow field surrounding the curve, but that with coals lower in fixed carbon the field widens out and the curve drops rapidly. The Pocahontas coals tested by Lord and Haas come close to the Mahler curve, and the average results of their tests of coals that are high in volatile matter and low in fixed carbon all fall within the Mahler field, except the Jackson Co. Ohio coal, which is slightly below it. Houghton's tests cover the breadth of the field and extend slightly above and below it, while the Wyoming coals are all below it. The Mahler curve is plotted from the figures given in the table on page 143.

The results of Mr. Houghton's tests are as follows:

	Coal Dry and Free from Ash.		
	Fixed Carbon. Per Cent.	Heating Value.	
		Calories.	B.T.U. per lb.
1. Youghiogheny, Pa.	62.6	8330	14,990
2. Pittsburgh, Pa.	60.6	7890	14,200
3. Vanderpool, Ky.	61.5	8000	14,400
4. Brier Hill, O.	61.8	7890	14,200
5. Hocking Valley, O.	57.5	7830	14,090
6. Big Muddy, Ill.	62.5	8080	14,540
7. Streator, Ill.	56.2	7890	14,200
8. Ladd, Ill.	56.8	8170	14,710
9. Seatonville, Ill.	54.7	8060	14,510
10. Wilmington, Ill.	57.1	7840	14,210
11. Mt. Olive. Ill.	57.1	7610	13,700
12. Indiana block	61.4	7950	14,310
13. Indiana lump	55.6	7670	13,810

Lord and Haas's tests cover only a small portion of the range of composition of the coals tested by Mahler. Mahler's tests, excluding

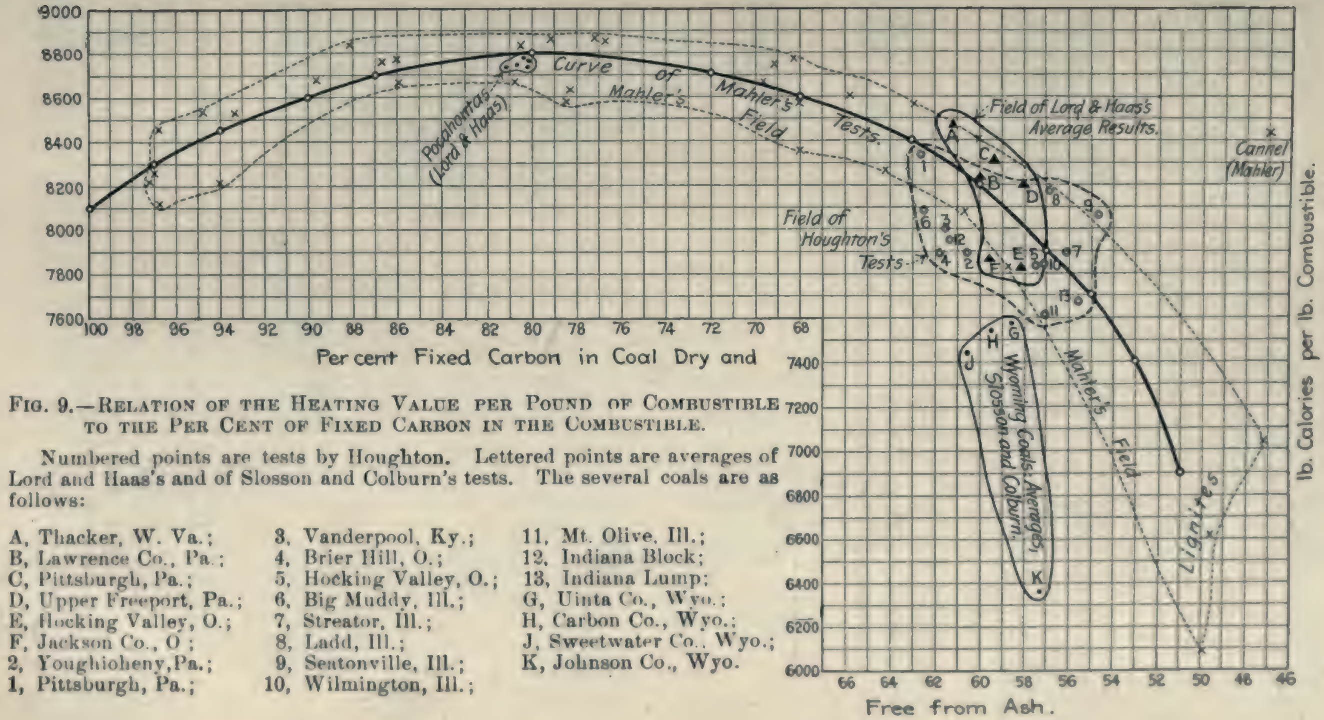

FIG. 9.—RELATION OF THE HEATING VALUE PER POUND OF COMBUSTIBLE TO THE PER CENT OF FIXED CARBON IN THE COMBUSTIBLE.

Numbered points are tests by Houghton. Lettered points are averages of Lord and Haas's and of Slosson and Colburn's tests. The several coals are as follows:

A, Thacker, W. Va.;
B, Lawrence Co., Pa.;
C, Pittsburgh, Pa.;
D, Upper Freeport, Pa.;
E, Hocking Valley, O.;
F, Jackson Co., O;
2, Youghioheny, Pa.;
1, Pittsburgh, Pa.;
3, Vanderpool, Ky.;
4, Brier Hill, O.;
5, Hocking Valley, O.;
6, Big Muddy, Ill.;
7, Streator, Ill.;
8, Ladd, Ill.;
9, Seatonville, Ill.;
10, Wilmington, Ill.;
11, Mt. Olive, Ill.;
12, Indiana Block;
13, Indiana Lump;
G, Uinta Co., Wyo.;
H, Carbon Co., Wyo.;
J, Sweetwater Co., Wyo.;
K, Johnson Co., Wyo.

the lignites, cover the entire range between 58 and 97 per cent of fixed carbon, while Lord and Haas's are confined between 55.7 and 62.2 per cent, except the five tests of Pocahontas coal, which are between 80.1 and 81.2 per cent. Excluding the coals that have below 58 per cent of fixed carbon in the combustible, the variation of any one of Lord and Haas's coals from the Mahler line does not exceed 320 calories, or 4 per cent. Taking the average figure for each class of coals, it falls in all cases within the limit of 3 per cent, except the Jackson Co. coal, the average of which is 4 per cent below. The figures from Houghton's tests also fall within the limit of 4 per cent variation from the Mahler line, except coal No. 4, Brier Hill, O., which falls 400 calories, or nearly 5 per cent, below the Mahler line. The Wyoming coals appear to belong to an entirely different class from any of the Eastern coals.

Heating Value of Wyoming Coals.—The following table is condensed from a report by Professors E. E. Slosson and L. C. Colburn of the University of Wyoming, Laramie, Wyo. (Special Bulletin, Jan., 1895.)

	Coal.						Combustible.		
	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Calories.	Fixed Carbon.	Calories.	B.T.U. per lb.
Uinta Co.	2.95	38.00	54.00	4.95	..	7467	58.70	8116	14,609
" "	8.82	33.55	51.75	5.90	..	6017	60.67	7055	12,699
Av. of 8	5.80	36.16	51.78	6.26	0.60	6673	58.39	7573	13,631
Carbon Co.	4.87	35.68	55.15	4.30	.77	7140	60.72	7863	14,153
" "	13.65	39.25	42.60	4.50	.80	5375	52.05	6567	11,821
Av. of 7	7.83	35.32	52.15	4.55	.71	6565	59.63	7540	13,572
Sweetwater Co.	5.55	36.95	55.70	1.80	.86	7358	60.12	7942	14,296
" "	14.23	37.48	46.07	2.22	.44	5949	55.14	7120	12,816
Av. of 13	8.65	34.86	53.69	2.71	.75	6598	60.63	7432	13,378
Johnson Co. 3 samples	13.55	35.05	45.30	6.10	..	5293	56.38	6587	11,857
	14.70	34.30	44.20	6.80	.34	4966	56.31	6326	11,387
	14.50	33.35	44.30	7.85	.42	4931	57.13	6350	11,450

The figures in the last three columns have been calculated by the author. The figures in the first two lines for each of the three counties first named are selected so as to show respectively the coals of the highest and the lowest heating value per pound of combustible of the samples tested. They show quite a large range of variation within the limits of a county. The heating value per pound combustible

apparently bears no definite relation to the percentage of fixed carbon in the combustible, indicating that the quality of the volatile matter is variable. Coals from Weston, Natrona, Albany, Fremont, Sheridan, Crook, and Converse counties are within the range of quality of the coals given in the table.

The Mahler calorimeter was used in determining the heating values.

The Calorific Power of Weathered Coals.—Messrs. R. S. Hale and Henry J. Williams of Boston, in Trans. Am. Soc. M. E., vol. xx., 1898, p. 333, give the results of analyses and calorimetric tests (by Mr. Williams's bomb calorimeter) of several coals which had been exposed to the weather for eleven months, and of duplicate samples

ANALYSES AND HEATING VALUES OF WEATHERED AND UNWEATHERED COALS.

Reference Letter.	Coal, Prox. Anal.		Ultimate Analysis of Combustible.					Combustible.			
	Moisture.	Ash.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Volatile Sulphur.	Fixed Carbon, per cent of Combustible.	Heating Value Calculated, B.T.U.	Heating Value by Calorimeter, B.T.U.	Loss by Weathering, B.T.U.
B	1.61	11.74	78.94	5.56	9.55	1.52	4.43	56.5	14,406		
Ax	1.91	12.61	79.59	4.89	9.75	1.54	4.23	56.9	14,065	....	341
C	1.21	8.69	83.54	5.69	5.87	1.63	3.27	63.6	15,403	15,461	
Dx	1.07	9.15	82.55	5.24	7.94	1.64	2.62	67.0	14,792	15,301	611‡
P	1.36	8.97	81.24	5.90	8.16	1.79	2.91	58.0	15,003		
Ex	0.89	10.02	81.56	5.67	8.14	1.69	2.94	57.8	14,908	....	95
R	1.07	8.77	82.47	6.01	6.81	1.88	2.83	56.5	15,353		
Sx	1.39	8.50	82.15	5.95	7.10	1.62	3.17	57.5	15,260	....	93
I	0.53	4.34	88.72	5.22	3.79	1.74	0.53	77.2	15,913		
Hx	1.12	6.32	88.05	5.04	4.08	1.78	1.04	75.8	15,705	....	208
K	2.02	10.08	81.45	5.62	10.19	1.66	1.09	61.2	14,622		gain
Jx	1.46	11.06	81.33	5.67	9.88	1.67	1.45	60.4	14,685	....	63
O	1.77	8.44	83.50	5.67	7.13	1.79	1.90	58.5	15,231	15,240	
Nx	1.71	10.47	82.41	5.74	8.39	1.67	1.79	61.4	15,011	15,200	220‡
L	0.95	5.75	88.85	5.19	3.03	2.07	0.87	78.2	15,989	16,048	
Mx	0.70	7.77	88.38	4.77	4.35	1.60	0.89	80.6	15,562	15,958	427‡
G*	0.79	7.51	88.90	4.82	2.87	2.04	1.37	80.0	15,799		
Po†	0.94	7.06	91.15	4.75	2.15	1.28	0.68	80.6	16,113		

* Indoors three years. † Exposed in a coal yard three years.

‡ 611, 220, and 427, loss in calculated values. 160, 40, and 90, corresponding loss by calorimeter tests.

Reference letters: B. C, etc., unweathered coals; Ax, Dx, etc., weathered coals; B, A, C, D, Yorkville lump, Porltand, Ohio; P. E. Pittsburg, Pa., fine; R. S. do., lump; I. H. New River, W. Va., fine; K. J, Nickel Plate, fine, McDonald Pa.; O, N, do., lump; L, G, M, Georges Creek, Cumberland, Md., fine; Po, Pocahontas, Va., fine.

of the same coals which had been sealed in glass jars. The results are condensed in the table on page 161. The following notes are extracted from the paper:

For tests of fine coal the samples were ground in a coffee-grinder, and thoroughly mixed and divided into two parts. For tests of lump coal the coals were broken into lumps of about nut size, and alternate lumps taken from the pile to form two samples. Where tests of both fine and lump coal were to be made, one sample was tightly sealed in an ordinary pint fruit jar, while the corresponding sample was exposed on an uncovered balcony out of doors for eleven months in an uncovered tin can provided with a diaphragm or bottom of fine wire gauze.

Rain and snow fell upon the coal, but the wire diaphragm permitted the water to drain off, while a paper disk placed upon the wire gauze prevented the coal from sifting through the meshes.

The lump samples were exposed in pans of much larger size, which were provided with holes to let the water drain off.

At the end of eleven months all the samples were analyzed by Mr. Henry J. Williams, together with a sample of Pocahontas coal that had been exposed in a coal-yard for three years, and one of Cumberland coal that had been under cover for three years.

In these analyses the percentages of ash in some of the exposed samples are unfortunately too high, for a little gravel was accidentally washed off the roof of the house, by the rain, into some of the cans. This, however, in no way affects the relative percentages of combustible matter free from ash.

The British thermal units are calculated from the analyses by the formula: $146C + 620(H - \frac{1}{8}O) + 40S$.

The average of the results obtained shows that weathering, under the conditions described, decreases the percentage of carbon, hydrogen, nitrogen; increases the percentage of oxygen, and does not materially alter the percentage of sulphur.

The conclusions to be drawn from an examination of the results shown are:

1st. That weathering decreases by about two per cent the theoretical calorific power, as calculated by Dulong's formula.

2d. That weathering decreases by about one-half of one per cent the actual or true calorific power, as shown by the three results obtained with the bomb.

The results obtained by Messrs. Hale and Williams are plotted on

the diagram given below, with relation to the fixed carbon in the combustible, together with the curve obtained from Mahler's tests. The diagram shows that all the coals containing over 59% fixed carbon in the combustible are within 3% of the corresponding position in the curve, with the exception of the result calculated from the ultimate analysis of the weather coal D. The exception is apparently due to an error in the analysis. The proximate analysis of this coal shows an increase in the fixed carbon by weathering of 3.68%, referred to combustible, while the ultimate analysis shows a decrease in the total carbon of 0.99%. These figures appear incompatible.

The coals containing less than 59% fixed carbon show, in most cases, a wide divergence from the curve, tending to confirm the con-

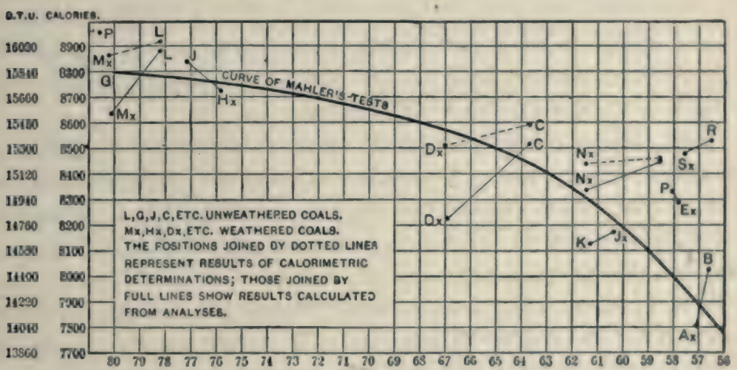

FIG. 10.—HEATING VALUE OF WEATHERED AND UNWEATHERED COALS.

clusion drawn from the work of Lord and Haas, that among the highly volatile coals each class of coal has a law of its own.

Coals AB and CD, both said to be Portland lump, from Yorkville, Ohio, show such a great difference in percentage of fixed carbon and in heating value that they appear to belong to entirely different classes of coal. It would be interesting to know whether these samples came from the same seam or from different seams. If from the same seam, the figures would indicate that the conclusion of Professors Lord and Haas, that the coals mined from one seam over a considerable area of country have a nearly uniform heating value, has some exceptions.

It should be noted that the loss in heating value per pound of the combustible portion of the coal may not be a true measure of the actual loss in heating value of the whole of a given lot of coal, for besides the loss in heating value per pound there may be also a loss in

weight, and this, if any, expressed as a percentage, should be added to the loss in heating value per pound. On the other hand, there may be a gain in weight due to oxidation. In most of these samples the oxygen seems to have increased.

Investigations of the deterioration by weathering of different types of coal were made in 1910 by the Bureau of Mines. To determine the loss of volatile matter during storage 20-pound samples were broken to ½-inch size at the mine and placed in bottles. At the laboratory the accumulated gas was withdrawn and a continuous escape of gas permitted at atmospheric pressure and temperature. Several coals were found to evolve methane in large volumes in the early period after mining, but the maximum loss in calorific value from this cause was only 0.16 per cent. (See Technical Paper No. 2, "The Escape of Gases from Coal.")

It seems therefore that the loss due to escape of volatile matter from coal has been greatly overestimated.

More elaborate tests were undertaken to determine the total loss possible in high-grade coal by weathering, and the extent of the saving to be accomplished by water submergence as compared to open-air storage, also whether salt water possessed any advantage over fresh water for this purpose.

Four kinds of coal were chosen: New River on account of its large use by the Navy, Pocahontas as a widely used steaming and coking coal in the eastern section, Pittsburgh coal as a type of rich coking and gas coal, and Sheridan (Wyo.) sub-bituminous or "black lignite"—a type much used in the West. With the New River coal, 50-lb. portions were crushed to ½-inch size and well mixed. These portions confined in perforated wooden boxes were submerged under sea water at three Navy Yards, differing widely from each other in climatic conditions, and 300-lb. portions from the same original lot were exposed to the open air, both out of doors and indoors, at the same places.

The New River coal showed a loss of less than 1 per cent calorific value in one year by weathering in the open. There was practically no loss at all in the samples submerged in either fresh or salt water. Pocahontas coal in a 120-ton pile on the Isthmus of Panama lost in one year less than 0.4 per cent in heating value.

The Pittsburgh gas coal during six months of outdoor exposure suffered no loss whatever of calorific value, measurable by the calori-

metric method used, not even in the upper surface layer of the bins. The Wyoming coal, however, sustained a loss of over 5 per cent.

Illinois coal has been found by Prof. S. W. Parr and Mr. A. Bement to suffer a loss in heating value of from 1 to 3 per cent on exposure for a year.

Weathering of Coal.—The practical effect of the weathering of coal, while sometimes increasing its absolute weight, is to diminish the quantity of carbon and disposable hydrogen and to increase the quantity of oxygen and of indisposable hydrogen. Hence a reduction in the calorific value.

An excess of pyrites in coal tends to produce rapid oxidation and mechanical disintegration of the mass, with development of heat, loss of coking power, and spontaneous ignition.

The only appreciable results of the weathering of anthracite within the ordinary limits of exposure of stocked coal are confined to the oxidation of its accessory pyrites. In coking coals, however, weathering reduces and finally destroys the coking power, while the pyrites are converted from the state of bisulphide into comparatively innocuous sulphates.

Richters found that at a temperature of 158° to 180° Fahr., three coals lost in fourteen days an average of 3.6% of calorific power.

It appears from the experiments of Richters and Reder that when there is no rise in the temperature of coal piled in heaps and left exposed to the air during nine to twelve months, it undergoes no sensible change in any respect; and that, on the other hand, when the coal becomes heated, it suffers precisely the same kind of change that was found by Richters to be effected in coal by heating it in contact with atmospheric air to a comparatively low temperature, namely loss of carbon and hydrogen by oxidation and increase of the absolute weight of the coal owing to the fixation of oxygen.*

Deterioration of Coal in Storage.—(A. Bement, *Power*, June 25, 1912.) Four samples of air-dry coal, 400 lbs. each, were stored in a box for a year. The box was covered with cheesecloth to exclude dirt. Two other samples were stored under water. The coals were analyzed and their heating power was determined by a Mahler calorimeter. The changes in weight and in heating power were as follows:

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* Reports of Second Geological Survey of Pennsylvania, vol. M.M., p. 113; also Percy's "Metallurgy: Refractory Materials and Fuel," 1873. See also papers by R. P. Rothwell, Trans. A. I. M. E., vol. iv, p. 55, and by I. P. Kimball, Trans. A. I. M. E., vol. viii, p. 204.

Coal.	A.	B.	C.	D.
Volatile matter in combustible, %	41.1	39.7	48.6	47.9
Heating power of comb., B.T.U.	15,048	14,575	14,350	14,250
CHANGE DUE TO EXPOSURE IN AIR FOR A YEAR				
Heating power, %	−.025	−0.38	−0.93	−1.85
Weight, %	0.00	+0.11	−1.15	−2.25
CHANGE AFTER STORAGE FOR A YEAR UNDER WATER				
Heating power, %	......	+0.02	......	−0.44
Weight, %	......	−0.81	......	−0.35

CHAPTER VI.

FUELS OTHER THAN COAL.

Coke.—Coke is the solid material left after evaporating the volatile ingredients of coal, either by means of partial combustion in furnaces called coke-ovens, or by distillation in the retorts of gas-works. Being a smokeless fuel it is available for use in the fire-boxes of internally fired boilers, which are not adapted to the smokeless combustion of soft coal, but its use for this purpose is quite limited on account of its cost.

The proportion of coke yielded by a given weight of coal is very different for different kinds of coal, ranging from 35 to 90 per cent.

Being of a porous texture, it readily attracts and retains water from the atmosphere, and sometimes, if it is kept without proper shelter, from 15 to 20 per cent of its gross weight consists of moisture.

ANALYSIS OF COKE.

(From report of John R. Procter, Kentucky Geological Survey.)

Where Made.	Fixed Carbon.	Ash.	Sulphur.
Connellsville, Pa. (Average of 3 samples)....	88.96	9.74	0.810
Chattanooga, Tenn. " 4 "	80.51	16.34	1.595
Birmingham, Ala. " 4 "	87.29	10.54	1.195
Pocahontas, Va. " 3 "	92.53	5.74	0.597
New River, W. Va. " 8 "	92.38	7.21	0.562
Big Stone Gap, Ky. " 7 "	93.23	5.69	0.749

Pressed Fuel or Briquettes.—A method of making pressed fuel from anthracite dust is described by E. F. Loiseau.* The dust is mixed with ten per cent of its bulk of dry pitch, which is prepared by separating from tar at a temperature of 572° F. the volatile matter it contains. The mixture is kept heated by steam to 212°, at which temperature the pitch acquires its cementing properties, and is passed between two rollers, on the periphery of which are milled out a series

* Trans. A. I. M. E., vol. viii, p. 314.

of semi-oval cavities. The lumps of the mixture, about the size of an egg, drop out under the rollers on an endless belt which carries them to a screen in eight minutes, which time is sufficient to cool the lumps, and they are then ready for delivery.

The enterprise of making the pressed fuel above described was not commercially successful, on account of the low price of other coal. In Europe, however, *"briquettes"* are regularly made of coal-dust (bituminous and semi-bituminous) and of lignite.

Tests of Briquettes.—Bulletin 403 of the U. S. Geological Survey, 1909, contains a report of comparative tests of run-of-mine semi-bituminous coal and the same coal briquetted, in a Normand water-tube marine boiler. The binder used in the briquettes was 6 per cent of water-gas pitch. On a boiler rating of 10 square feet per H. P. tests were made at several rates of driving from 100 to 300 per cent of rating. Practically no difference was found in efficiency between the coal and the briquettes. In both the equivalent evaporation per pound of dry coal fired was about 10 lbs. and 100 per cent of rating and 8 lbs. at 300 per cent. The furnace conditions were in general better at the higher rates, the air supply at the lower rates of driving being excessive. The briquettes made as much (or more) smoke as run-of-mine coal, and with briquettes the storage capacity of a bunker is reduced by 23 to 27 per cent.

In 1910 the German Empire produced 19,561,494 metric tons of briquettes, of which 15,120,255 metric tons, or 77 per cent of the total output, were made from lignite. These lignite briquettes are much liked for domestic use, and form the chief household fuel in many large cities.

The U. S. Geological Survey in 1904 investigated the merits of lignite as a fuel, with the object of ascertaining the most efficient methods of utilizing it. Briquetting tests of lignite were made and also combustion tests of lignite briquettes and of raw lignite in boiler furnaces and in gas producers. (See Geological Survey Bulletins 261, 290, 332, 343, and 363, Professional Paper 48.)

Briquetting tests of lignite were undertaken in 1909 by the U. S. Bureau of Mines to ascertain:

1. The possibility of briquetting American lignites without adding binder to them.
2. The suitability of the German brown-coal briquette presses for briquetting American lignites.
3. The percentage of moisture needed in the briquette material to give the best briquettes.
4. The approximate commercial cost of briquetting lignites.
5. The weathering qualities of briquettes as compared with raw lignites.

The results were not conclusive, but they warrant the continuation of the investigations as soon as funds are available for the purpose. Enough testing was done to indicate that some American lignites equal German lignites in fuel value and can probably be made into briquettes on a commercial scale without the use of binding materials. Three samples of lignite, one from Texas, one from North Dakota, and one from California, were made into satisfactory briquettes without the addition of a binder. It was proved that some lignites after having slacked by exposure can be made into briquettes without the use of binding material. Cohesion and weathering tests demonstrated that good briquettes endure handling and resist weathering much better than the lignite from which they are made. Bulletin 14, U. S. Bureau of Mines.

Experiments on briquetting of anthracite culm and a description of a briquetting plant are given in a paper by Chas. Dorrance, Jr., in Trans. A. I. M. E., 1911.

Briquetted Coal in Locomotives.—The results of a series of tests with raw and briquetted coal made at the locomotive testing plant of the Penna. R. R. Co. were reported at the annual meeting of the Am. Rwy. Master Mechanics Assn. in 1908.

The accompanying table taken from a plot of actual results shows comparatively the evaporation of the natural and briquetted coal.

BOILER EVAPORATION WITH RAW AND BRIQUETTED FUEL.

Rate of Evaporation per Square Foot Heating Surface.	Equivalent Evaporation per Pound of Fuel.	
	Natural Lloydell Coal.	Briquetted Coal.
8 lbs.	9.5 lbs.	10.7 lbs.
10 "	8.8 "	10.2 "
12 "	8.0 "	9.7 "
14 "	7.3 "	9.2 "
16 "	6.6 "	8.7 "

The quantity of cinders collected in the smoke-box showed no material difference as between the raw coal and the briquetted coal.

Fire-box and smoke-box temperatures were practically the same at the same rates of evaporation, whether the coal was used in its raw state or briquetted.

The apparent reason for the increased evaporation per pound of fuel with the briquetted coal is that, although the loss due to cinders in the smoke-box is not different as judged by the quantity collected, the calorific value of the cinders from the briquetted coal was lower than with raw coal, and, further, on account of the uniform size of the briquetted fuel the distribution of air through the fire permitted more complete combustion and liberation of heat than with the raw coal.

Binders for Coal Briquettes.—The results of experiments on the use of different materials as binders for briquetting coal are reported in Bulletin 343 of the U. S. Geological Survey, 1908.

The experiments show that, in general, for plants situated where it can be obtained, the cheapest binder will prove to be the heavy residuum from petroleum, often known to the trade as asphalt. Four per cent of this binder being sufficient, its cost ranges from 45 to 60 cts. per ton of briquettes produced. This binder is particularly available in California, Texas and adjacent territory. Second in order of importance comes water-gas tar pitch. Five or six per cent usually proving sufficient, the cost of this binder ranges from 50 to 60 cts. per ton of briquettes produced. As water-gas pitch is also derived from petroleum, it will be available more particularly in oil-producing regions. Third in order of importance is coal-tar pitch. Being derived from coal, this binder is very widely available. From 6.5 to 8 per cent will usually be required, and the cost ranges from 65 to 90 cts. per ton of briquettes produced.

The briquetting of lignite offers a peculiarly difficult problem. If the lignite cakes in the fire, asphaltic residues from petroleum or water-gas tar pitch may be used as binder, larger percentages being required than for ordinary coals. The most promising binders for lignites that do not cake are starch, sulphite liquor from paper mills, and magnesia. Lignites may be briquetted without binder if they are to be burned on grates especially constructed to overcome the tendency to fall to pieces in the fire.

The main problem in briquetting is to find a suitable binding material at sufficiently low cost. When the difference in price between the slack coal and the first-class lump coal is $1, the cost of briquetting should not exceed this amount. Of this the binder must cost less than 60 cents per ton, as the cost of manufacture averages about 40 cents.

Coal-dust.—Dust when mixed in air burns with such extreme rapidity as in some cases to cause explosions. Explosions of flour-mills have been attributed to ignition of the dust in confined passages. Experiments made in Germany in 1893 show that pulverized fuel may be burned without smoke, and with high economy. The fuel, instead of being introduced into the fire-box in the ordinary manner, is first reduced to a powder by pulverizers of any construction. In the place of the ordinary boiler fire-box there is a combustion-chamber in the form of a closed furnace lined with fire-brick and provided with an air-injector similar in construction to those used in oil-burning furnaces. The nozzle throws a constant stream of the fuel into the chamber. This nozzle is so located that it scatters the powder throughout the whole space of the fire-box. When this powder is once

ignited, which is readily done by first raising the lining to a high temperature by an open fire, the combustion continues in a regular manner under the action of the current of air which carries it in.

Powdered fuel was used in the Compton rotary puddling-furnace at Woolwich Arsenal, England, in 1873.* It is used with great success in this country in the rotary kilns used in the manufacture of Portland cement.

The *American Manufacturer* of Dec. 13, 1900, illustrates the Cyclone Pulverizer, a British invention, which is said to be in successful use grinding coal for dust-firing. We quote from it the following statement of the requisite conditions of success in the use of powdered fuel, and of the advantages claimed for it:

The best results can only be obtained when the following essentials are complied with, viz.:

(*a*) The fuel must be reduced cheaply to a very finely divided powder, and must be of a strictly uniform grade.

(*b*) The coal-powder mixed with air must be carried in an unbroken stream into the combustion-chamber.

(*c*) The air current must be so regulated that it will hold the coal-powder in suspension, when within the furnace, until complete combustion is effected.

(*d*) A sufficiently high temperature must be continuously maintained in the furnace, to ensure perfect combustion of the powder.

The problem of how to reduce the coal economically to the required standards of fineness and uniformity is the one thing which has given great trouble in developing new devices in firing-apparatus.

The advantages of the use of powdered fuel may be summarized as follows: 1. The most economical and complete combustion of the fuel, in a manner similar to gas-firing, but without the disadvantages of that system. 2. Complete smokelessness. 3. Reduced labor expenses, since one man can easily manage several furnaces. 4. Adaptability and ease of regulation to meet any requirements, especially when the work is that of steam-generation. 5. Decreased wear and tear of furnaces, in the case of internally fired boilers. 6. Saving of time in starting up furnaces, and rapid stoppage of firing, in case of necessity. 7. Less labor in removing refuse, which is light in quantity, and in the form of slag. 8. Intimate contact of the fuel with the air, whereby the minimum excess over the theoretical volume is employed, and waste of heat thus avoided.

Notwithstanding the advantages above stated, there is no prospect that the use of powdered coal for steam making will ever become extensive. F. R. Low, in a paper on Pulverized Coal for Steam Making,

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* Journal of the Iron and Steel Institute, i., 1873, p. 91.

(*Jour. A. S. M. E.*, Oct. 1914), says: Numerous attempts have been made in the past quarter century to use pulverized coal as a boiler fuel. The published accounts of the various trials are full of promise and apparent accomplishment, but few of the processes have persisted, and only a small proportion of the coal used in steam making is fired in this way. The cost of pulverizing and the large initial cost of the drying, pulverizing, conveying and feeding apparatus, together with the fact that coal of practically all grades can be burned with a tolerable degree of smokelessness in the cheaper apparatus in common use with a degree of efficiency which leaves little margin to cover the increased expenditure, have combined to restrict the use of pulverized coal for boiler purposes to special instances.

Peat or Turf, as usually dried in the air, contains from 25% to 30% of water, which must be allowed for in estimating its heat of combustion. This water having been evaporated, the analysis of M. Regnault gives, in 100 parts of perfectly dry peat of the best quality: C 58%, H 6%, O 31%, Ash 5%.

In some examples of peat the quantity of ash is greater, amounting to 7% and sometimes to 11%. The specific gravity of peat in its ordinary state is about 0.4 or 0.5. It can be compressed by machinery to a much greater density. (Rankine.)

Clark ("Steam-engine," vol. i, p. 61) gives as the average composition of dried Irish peat: C 59%, H 6%, O 30%, N 1.25%, Ash 4%.

Applying Dulong's formula to this analysis, we obtain for the total heating value of perfectly dry peat 10,009 heat-units per pound, and for air-dried peat containing 25% of moisture 7507 heat-units per pound. To determine the "available" heating value, we must subtract the heat lost in the superheated steam in the chimney-gases, as calculated by the formula on page 26. For each pound of the air-dried peat the superheated steam is $0.25 + 0.75 \times .06 \times 9 = 0.655$ lbs.; and if the temperature of the chimney-gases is 462° and that of the air-supply 62° the heat lost is

$$0.655 \times [(212 - 62) + 970 + (0.48 \times 250)] = 812 \text{ B.T.U.}$$

This subtracted from 7507 gives 6695 B.T.U. as the available heating value per pound of peat.

Deposits of peat are found in many places throughout the United States and Canada, but it has hitherto not been found practicable, commercially, to utilize them for fuel in competition with coal. In

some countries in Europe, such as in Holland and Denmark, the peat industry is quite common. Papers on peat and its utilization will be found in "Mineral Industry," vol. ii., 1893, and vol. vii., 1898. The following table is given showing the comparative and calorimetric value, analyses of wood, peat, and coal, from a report made in Sweden in 1896. The analyses are of the fuel dry and free from ash.

Composition.	Wood.	Peat.	Brown Coal.	Swedish Coal.	English Steam Coal.	Welsh Anthracite.
Carbon........	52.0	58.0	66.0	78.0	81.0	91.0
Hydrogen.....	6.2	5.7	4.6	5.1	5.2	3.5
Oxygen.......	41.7	35.0	28.0	14.8	11.5	3.5
Sulphur.......	....	.....	.....	0.8	1.0	1.0
Nitrogen......	0.1	1.2	1.0	1.3	1.3	1.0
Calories.......	4900	5,700	6,000	7,500	8,000	8,600
B. T. U........	8920	10,260	10,800	13,500	14,400	15,480
Moisture......	20	22	25	13.5	7.6	2.0

Production of Peat Fuel in the United States.—The production and uses of peat for fuel and other purposes are discussed by Charles A. Davis in "Mineral Resources," 1910 (U. S. Geological Survey) and also in Bulletin 16 of the U. S. Bureau of Mines, 1911. He says:

As yet no peat-fuel industry can be said to exist in the United States, although much experimental work has been done and great sums of money spent to establish one. In Europe the peat beds of various nations are the source of raw materials for industries of some magnitude, although their development is still in an experimental stage.

The only peat-fuel plant erected in the United States in 1910 was that of the Peat Products Co., at Lakeville, Ind. The peat is dug by a centrifugal pump, pumped to storage bins, and, after some of the water has drained away, dried in a drier heated by exhaust steam and stack gases. When dry, the peat is reduced to powder, conveyed to a press, and compressed into compact briquettes. The production of peat for fuel in the United States during 1910 was very small. No figures have been obtainable as to their production.

Peat fuel may be said to be especially useful for certain purposes for which wood was formerly in general use and for which coal has not yet been altogether successfully introduced, such as brick and other forms of ceramic firing and lime burning. It appears to reach its highest value, however, as a source of producer gas in properly constructed gas producers. Although the outlook and

European experience warrant further investigation of its possible uses and value, no final conclusions as to the commercial value of American peat as compared with coal can be reached.

During a part of 1910 the Mines Branch of the Canada Department of Mines operated on a commercial basis a demonstration peat-fuel plant. This was located at Alfred, Ontario, about 30 miles from Ottawa, and was equipped with Swedish machinery. Part of the 1600 tons of air-dried machine peat produced by the plant was sold, and part was used in the gas-producer plant established by the Government in Ottawa for testing peat, lignite, and similar fuel. These plants are fully described in Bull. 4, Can. Dept. of Mines, Mines Branch, 2d edition, 1910.

Wood.—Wood, when newly felled, contains a proportion of moisture which varies greatly in different kinds and in different specimens, ranging between 30% and 50%, and being on an average about 40%. After eight or twelve months' ordinary drying in the air the proportion of moisture is from 20% to 25%. This degree of dryness, or almost perfect dryness if required, can be produced in a few days' drying in an oven supplied with air at about 240° F.

Perfectly dry wood contains about 50% of carbon, the remainder consisting almost entirely of oxygen and hydrogen in nearly the proportions which form water, the hydrogen being somewhat in excess. The coniferous family contains a small quantity of turpentine, which is a hydrocarbon.

ANALYSIS OF WOODS, BY M. EUGENE CHEVANDIER.

Woods.	Composition.				
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Beech	49.36%	6.01%	42.69%	0.91%	1.06%
Oak	49.64	5.92	41.16	1.29	1.97
Birch	50.20	6.20	41.62	1.15	0.81
Poplar	49.37	6.21	41.60	0.96	1.86
Willow	49.96	5.96	39.56	0.96	3.37
Average	49.70%	6.06%	41.30%	1.05%	1.80%

Heating Value of Wood.—According to a table by S. P. Sharpless,* the ash varies from 0.03% to 1.20% in American woods, and the fuel

* Journal of the Charcoal Iron Workers' Association, vol. iv, p. 36.

value ranges from 3667 (for white oak) to 5546 calories (for long-leaf pine) = 6600 to 9883 British thermal units for dry wood.

The following table is given in several books of reference, the authority and quality of coal referred to not being stated.

The weight of one cord of different woods (thoroughly air-dried) is about as follows:

Hickory or hard maple	4500 lbs.	equal to	1800 lbs. coal.	(Others give	2000.)
White oak	3850	" "	1540 "	("	1715.)
Beech, red and black oak	3250	" "	1300 "	("	1450.)
Poplar, chestnut, and elm	2350	" "	940 "	("	1050.)
The average pine	2000	" "	800 "	("	925.)

Referring to the figures in the last column, it is said:

From the above it is safe to assume that $2\frac{1}{4}$ lbs. of dry wood are equal to 1 lb. average quality of soft coal and that the fuel value of the same weight of different woods is very nearly the same—that is, a pound of hickory is worth no more for fuel than a pound of pine, assuming both to be dry. It is important that the wood be dry, as each 10% of water or moisture in wood will detract about 12% from its value as fuel.

Taking an average wood of the analysis, perfectly dry, C. 50; H, 6; O, 42; N and ash, 2, its total heating value, by Dulong's formula, is 7765 B.T.U. per pound. If the wood contains 25% of moisture the analysis of the moist wood is C, 37.5; H, 4.5; O, 31.5; N and ash, 1.5, and its total heating value is 75% of 7765, or 5824 B.T.U. per pound. To obtain the "available" heating value we subtract the loss of heat in the steam formed from the water and the hydrogen in the wood, as calculated by the formula on page 26. Taking the temperature of the air supply at 62° and that of the escaping chimney-gases at 462°, this loss is 810 B.T.U., which subtracted from 5824 gives 5014 B.T.U. per pound as the available heating value.

Sawdust.—The heating power of sawdust is naturally the same per pound as that of the wood from which it is derived, but if allowed to get wet it is more like spent tan (which see below). The conditions necessary for burning sawdust are that plenty of room should be given it in the furnace, and sufficient air supplied on the surface of the mass. The same applies to shavings, refuse lumber, etc. Sawdust is frequently burned in sawmills, etc., by being thrown into the furnace by a fan-blast.

Wet Tan-bark.—Tan, or oak-bark, after having been used in the processes of tanning, is burned for fuel. The spent tan consists of the fibrous portion of the bark. According to M. Peclet, five parts of oak-bark produce four parts of dry tan; and the heating power of perfectly dry tan, containing 15% of ash, is 6100 British thermal units; whilst that of tan in an ordinary state of dryness, containing 30% of water, is only 4284 B.T.U.*

The principal cause of poor economy in the burning of tan bark, besides the difficulty of securing good combustion in the furnace, is the amount of heat that is carried away in the shape of superheated steam in the chimney gases. If the bark, after being partly dried by compression, were further dried in a rotary drier by the waste heat from the chimney gases, there would be a very important gain in economy. The following calculation shows the theoretical results that may be obtained in burning tan bark of different degrees of moisture under certain assumed conditions. The dry bark is assumed to have the composition $C = 0.50$; $H = 0.06$; $O = 0.40$; N and ash $= 0.04$. Heating value by Dulong's formula 7920 B.T.U. per lb. Bark containing 20 per cent moisture would have a heating value of $0.80 \times 7920 = 6336$ B. T. U.

Assuming the chimney gases to escape at 600°, the heat required to evaporate 1 lb. water from 62°, and to superheat the steam to 600 would be $(212 - 62) + 970 + 0.48\ (600 - 212) = 1306$, or for 20 per cent moisture, 261 B. T. U. per pound of tan.

The 0.06 lb. of H in a pound of dry tan will unite with $0.06 \times 8 = 0.48$ O, making 0.54 lb. H_2O, which escapes as superheated steam, carrying away $0.54 \times 1306 = 705$ B. T. U. for each pound of dry tan or $0.80 \times 705 = 564$ B. T. U. for tan with 20 per cent moisture.

Assuming 25 lb. of air to be required per lb. of C + H in the fuel or $25 \times 0.56 = 14$ lb. of dry tan, the heat carried away by this air heated to 600° is $0.24 \times 14 \times (600-62) = 1808$ B.T.U. per lb. of dry tan or 1446 B.T.U. for tan with 20 per cent moisture. Using the figures thus found the following table is constructed:

* David Moffatt Myers (Trans. A.S.M.E., 1909,) gives the average heating value of dry hemlock tan, as found by a bomb calorimeter in six tests by Dr. Sherman, as 9504 B.T.U. The composition of dry tan is ash, 1.42; C, 51.80; H, 6.04; O, 40.74. By Dulong's formula the heating value would be 8152 B.T.U.

Moisture.	B.T.U. per lb. Wet Tan.	Losses of Heat Due to			Net Heat Value, B.T.U.	Efficiency, Per Cent.	Lb. Evap. per lb. Wet Tan.
		Moisture.	H in Fuel.	Heating Air.			
0.20	6336	261	564	1446	4065	64.2	4.19
0.30	5544	392	493	1266	3393	61.2	3.50
0.40	4752	522	423	1085	2772	57.3	2.81
0.50	3960	653	352	904	2051	51.8	2.11
0.60	3168	784	282	723	1379	43.5	1.42
0.70	2376	914	211	542	709	29.8	0.73
0.80	1584	1045	141	362	36	2.5	0.03

Suppose that tan with 60 per cent moisture were dried to 20 per cent before being put into the furnace, using for this purpose the waste heat of the chimney gases, we would then have 0.40 dry tan + 0.60 moisture dried to 0.40 dry tan + 0.10 moisture, 0.50 water being removed. If the moisture and the waste gases left the drying chamber at 300° then each pound of moisture would take (212 — 62) + 970 + 0.48 (300—212) = 1162 B. T. U. and 0.6 lb. would take 697 B. T. U. The H in the 0.40 lb. of dry tan would make 0.216 H_2O, which would take away 0.216 × 1162 = 251 B. T. U. Heating the air would take 0.40 × 14 × 0.24 × (300 — 62) = 320 B. T. U. The sum of these is 1268, which subtracted from 3168, the total heating value of tan with 60 per cent moisture, leaves a net value of 1900 instead of 1379, the figure given in the table. The efficiency would be 1900 ÷ 3168 = 60.0 per cent, instead of 43.5 per cent, and the evaporation from and at 212° 1900 ÷ 970 = 1.96 lbs. instead of 1.42 lbs.

Straw as Fuel.—Experiments in Russia showed that winter-wheat straw, dried at 230°F., had the following composition: C, 46.1; H, 5.6; N, 0.42; O, 43.7; Ash, 4.1. Heating value in British thermal units: dry straw, 6290; with 10% water, 5448. With straws of other grains the heating value of dry straw ranged from 5590 for buckwheat to 6750 for flax.*

Clark ("Steam-engine," vol. i, p. 62) gives the mean composition of wheat and barley straw as C, 36; H, 5; O, 38; N, 0.50; Ash, 4.75; water, 15.75, the two straws varying less than 1%. The total heating value of straw of this composition, according to Dulong's formula, is 5411 heat-units. Clark erroneously gives it as 8144 heat-units. Taking the temperature of the chimney-gases at 462° and

* *Eng. Mechanics*, Feb., 1893, p. 55.

that of the air-supply at 62° the "available" heating value is 4660 B.T.U.

Bagasse as Fuel in Sugar Manufacture.—Bagasse is the name given to refuse sugar-cane, after the juice has been extracted. Prof. L. A. Becuel, in a paper read before the Louisiana Sugar Chemists' Association, in 1892, says: "With tropical cane containing 12.5% woody fibre, a juice containing 16.13% solids, and 83.87% water, bagasse of, say, 66% and 72% mill extraction would have the following percentage composition:

	Woody Fibre.	Combustible Salts.	Water.
66% bagasse	37	10	53
72% bagasse	45	9	46

"Assuming that the woody fibre contains 51% carbon, the sugar and other combustible matters an average of 42.1%, and that 12,906 units of heat are generated for every pound of carbon consumed, the 66% bagasse is capable of generating 2978 heat-units per pound as against 3452, or a difference of 474 units in favor of the 72% bagasse.

"Assuming the temperature of the waste gases to be 450° F., that of the surrounding atmosphere and water in the bagasse at 86° F., and the quantity of air necessary for the combustion of one pound of carbon at 24 lbs., the lost heat will be as follows: In the waste gases, heating air from 86° to 450° F., and in vaporizing the moisture, etc., the 66% bagasse will require 1125, and the 72% bagasse 1161 heat-units.

"Subtracting these quantities from the above, we find that the 66% bagasse will produce 1853 available heat-units, or nearly 38% less than the 72% bagasse, which gives 2990 units.

"It appears that with the best boiler plants, those taking up all the available heat generated, by using this heat economically the bagasse can be made to supply all the fuel required by our sugar-houses."

The figures given below are taken from an article by Samuel Vickess (*The Engineer*, Chicago, April 1, 1903).

When canes with 12 per cent fiber are ground, the juice extractions and liquid left in the residual bagasse are generally as shown in the following table:

With	Per Cent of Normal Juice Extracted on Weight of Cane.	Per Cent of Liquid Left in Bagasse on Weight of Bagasse.
Double crushing	70	60
Single crushing	62	68
Crusher and double crushing	72	57
Triple crushing	76	50
Crusher and triple crushing with saturation	82	50

The value of bagasse as a fuel depends upon the amount of woody fiber it contains, and the amount of combustible matter (sucrose, glucose, and gums), held in the liquid it retains. 100 lbs. cane with triple crushing gives 76 lbs. juice, and 24 lbs. bagasse, which consists of 12 lbs. fiber and 12 lbs. juice. The 12 lbs. of juice contains 16 per cent or 1.92 lbs. sucrose, 0.5 per cent or 0.06 lb. glucose, 2.5 per cent other organic matter and 1 per cent or 0.12 lb. ash, making a total of 20 per cent or 2.4 lbs. of solid matter, and 80 per cent or 9.6 lbs. of water. Reducing these figures to quantities corresponding to 1 lb. of bagasse, and multiplying by the heating values of the several substances as given by Stohlmann, we find the heating value of the combustible in 1 lb. of bagasse as follows:

0.5	lb. fiber	×7461 =	3730 B.T.U.
0.08	lb. sucrose	×6957 =	557 "
0.0025	lb. glucose	×6646 =	17 "
0.0125	lb. org. matter	×7461 =	93 "
0.4	lb. water		4397
0.005	lb. ash		
1.0000			

This 4397 B. T. U. is the gross heating value, which would be obtained in a calorimeter in which the products of combustion were cooled to the temperature of the atmosphere. To find approximately the heat available for generating steam in a boiler we may assume that 10 lbs. of air is used in burning each pound of bagasse, that the atmospheric temperature is 82° and the flue gas temperature 462°, and that in addition to the 0.4 lb. water per lb. bagasse one-half of the remaining 0.6 lb. is oxygen and hydrogen in proportions which form water, making 0.7 lb. water which escapes in the flue gas as superheated steam. The heat lost in the flue gases per pound of bagasse is [$10 \times 0.24 \times (462 - 82) + 0.7\,(212 - 82) + 970$

$+ 0.5\ (462 - 212)] = 1770$ B.T.U., which subtracted from 4397 leaves 2627 B. T. U. as the net or available heating value, which is equivalent to an evaporation of 2.7 lbs. of water from and at 212°. Mr. Vickess states that in practice 1 lb. of such green bagasse evaporates 2 to 2¼ lbs. from feed water at 100° into steam at 90 lbs. pressure. This is equivalent to from 2.31 to 2.59 lbs. from and at 212°.

Drying Bagasse with the Waste Heat from Boilers.—Prof. E. W. Kerr, in Bulletin No. 128 of the Agricultural Experiment Station of the Louisiana State University, 1911, describes a series of about 40 boiler tests, some with wet bagasse and some with bagasse that had been partially dried by contact with boiler flue gases in an experimental drying apparatus. It was found that there was no danger of setting the bagasse on fire in the drier as long as it was kept moving. The average temperature of the gases entering the drier was 474° F., and that leaving the drier, 219°. The principal conclusions of the paper are as follows:

For bagasse with 52% moisture, which is not far from the average in Louisiana, 16% of the heat generated is required to evaporate the moisture in the bagasse and raise its temperature to that of the stack.

The heat wasted in the stack gases varies with the efficiency of the boiler and furnace. Theoretically, the heat thus wasted is more than sufficient to evaporate all the moisture from the bagasse by the use of an efficient dryer. With bagasse having 52% moisture and a boiler having 60% efficiency, the efficiency of the drier would have to be only 60% in order to remove all of the moisture from the bagasse.

The average moisture in the bagasse entering the drier was 54.3%, and, leaving it, 46.4%, which means that 14.5% of the moisture in the bagasse was removed by the drying process.

The average equivalent evaporation from and at 212° F. per lb. of wet bagasse burned was 1.63 lbs. and that for the partially dried bagasse, 2.53 lbs. One pound of the partially dried bagasse had a heat value of 55.2% greater than that of 1 lb of wet bagasse.

The average boiler efficiency for the tests with the drier in use was 63.5% and that with undried bagasse, 50.7%. The increased efficiency with partially dried bagasse is probably due to less smoldering during combustion and to higher furnace temperatures.

Based on an equivalent evaporation of 14 pounds of water from and at 212° per pound of oil, the saving due to drying was calculated to be 2.57 gallons of oil per ton of cane. For a grinding of 60,000 tons this would give a total saving of 3673 barrels of oil.

Petroleum.—Thos. Urquhart of Russia gives the following table of the theoretical evaporative power of petroleum in comparison with that of coal, as determined by Messrs. Favre and Silbermann:*

* Proc. Inst. M. E. Jan., 1889.

Fuel.	Specific Gravity at 32° F., Water = 1.000.	Chem. Comp.			Heating power, British Thermal Units.	Theoret. Evap., lbs. Water per lb. Fuel, from and at 212° F.
		C. %	H. %	O. %		
Penna. heavy crude oil. .	0.886	84.9	13.7	1.4	20,736	21.48
Caucasian light crude oil.	0.884	86.3	13.6	0.1	22,027	22.70
" heavy " .	0.938	86.6	12.3	1.1	20,138	20.85
Russian naphtha refuse. .	0.928	87.1	11.7	1.2	19,832	20.53
Good English coal, mean of 98 samples.	1.380	80.0	5.0	8.0	14,112	14.61

In experiments on Russian railways with petroleum as fuel, Mr. Urquhart obtained an actual efficiency equal to 82% of the theoretical heating value. The petroleum is fed to the furnace by means of a spray-injector driven by steam. An induced current of air is carried in around the injector-nozzle, and additional air is supplied at the bottom of the furnace.

The following notes are condensed from a paper on "Crude Petroleum and its Products as Fuel," by R. H. Tweddle.*

Crude petroleum is a hydrocarbon, often containing a small percentage of sulphur and oxygen as impurities. Its specific gravity may vary from 12° to 70° Baumé, but the greatest quantity produced ranges from 30° to 45° Baumé. The color of crude petroleum is usually a green brown, but it is found from a light brown color, through the various shades of green to a jet black. It may be broken up by distillation into benzene, kerosene, and other distillates and residuums of various qualities, any one of which makes a very good fuel under certain conditions.

Gasolene, or petroleum distillate of more than 74° Baumé, will never be used for fuel except to a very limited extent, since it and its closely associated distillates are always more valuable for other purposes. [It is extensively used in internal combustion engines.]

Benzene, or petroleum distillate from 55° to 74° Baumé, is the best of all liquid fuels, but its use is restricted owing to the care with which it has to be handled. The difficulty, danger and expense of transporting will only allow of its use in a very few favored localities.

Kerosene or petroleum distillate of from 48° B to 35° B gravity is an excellent fuel, but, owing to the expense attending its preparation, we can hardly expect to see the price fall below 3c. per gallon,

* *Engineering and Mining Journal*, Oct. 14, 21, and 28, 1899.

except in the places where it is produced; for, should it generally become so cheap the consumption of it as an illuminant would increase so enormously that there would be little left for fuel.

The present price of kerosene in bulk and in large quantity may be taken at about 3c. per gallon at its place of production, both in Russia and America. As a fuel for small boilers it is the best, because of its portability and the safety and facility with which it can be handled.

Next to kerosene, some of the heavy distillates of petroleum known as neutral or solar oils could be used as fuel, but they have no particular advantage over kerosene, save their high fire-test.

Crude petroleum may contain any portion of benzene and kerosene from nothing up to nearly 90 per cent, varying entirely with the locality where it is produced. We may say roughly that of these two distillates, American crude petroleum contains 50 to 75 per cent of kerosene and benzene; Russian from 15 to 50 per cent; Peruvian from 15 to 50 per cent.

If distillation is stopped after the benzenes and kerosenes have been run off, there remains in the still an oil known by the various names of residuum, reduced oil, tar, fuel-oil, astatki, mazoot, petroleum refuse, etc.

If the distillation of this residuum is pushed still farther, neutral and lubricating oils distill over, or else, with certain forms of stills, decomposition sets in, and various products may be distilled over, until nothing but a small amount of coke is left in the still.

The demand for mineral lubricating oils is so great in the United States that but little residuum would be placed on the market at a price which would render it available as a fuel-oil. In Russia, however, where the crude oil contains a low percentage of kerosene, there is an enormous surplus of residuum, which cannot all be used for the manufacture of lubricating oils. It is generally known as "astatki" or "mazoot," and is used for fuel in all possible places. This astatki is the fuel-oil par excellence for marine and locomotive work where a perfectly safe oil is required. It is now distributed largely over the Russian Empire, and in 1890 some 600,000 tons were used for interior navigation in Russia alone, and the consumption has been constantly increasing.

The eastern petroleum region of the United States is about 400 miles from the seaboard, and although many pipe-lines traverse this

distance, there must be an expense connected with the carriage of the crude oil. The petroleum fuel consumed in the United States is almost restricted to the use of crude oil, and this is not the fuel which will suit the general consumer, especially if he is to use the oil for either railroad or marine purposes. Crude oil is a most excellent and easily handled fuel, but it must be used with caution, and is absolutely unfit for use on a locomotive or steamer, since, in case of accident, it may catch fire and spread with startling rapidity. For such purposes no petroleum should be used that has a fire-test of less than 200° to 250° Fahrenheit. A petroleum oil with a fire-test of 250° F. is a safer fuel than coal.

Residuum oil which has a fire-test of say 250° to 300° F. is the most suitable for fuel on steamers, since it is absolutely safe, as it cannot take fire and does not give off inflammable gases until heated to a temperature above that of boiling water. As the fuel would be carried in tanks below the water-line, heating to that degree becomes a practical impossibility. Such oil may be placed in a bucket and stirred with a red-hot poker without catching fire; shovelfuls of hot coals may be thrown into it, but they will sink and be extinguished the same as if thrown in water.

It is probable that in the future petroleum fuel will be used more for marine purposes on account of economy in space and weight. California petroleum will probably be largely used for this purpose, as the production of crude petroleum there is being rapidly increased, and the oil is better suited by its quality for fuel than for refining purposes, owing to the small proportion of volatile constituents and large proportion of heavy hydrocarbons. It is just the contrary with the petroleum found in the Eastern States, which is especially adapted to the manufacture of illuminating oils, owing to the large proportion of volatile hydrocarbons it contains.

The petroleum-fields of Peru somewhat resemble those of California, and are most favorably situated close to the sea. The crude oil is a good fuel for stationary boilers, and, if 40 per cent of benzene and kerosene are distilled off, the resulting residuum is an oil of about 22° B. gravity and 260° to 280° fire-test, of moderate viscosity and containing no paraffine. It preserves its fluidity at low temperatures, and makes an excellent fuel for either locomotive or marine use. The price at which it can be supplied is $5.00 to $7.50 per ton. As good coal on the west coast of South America seldom reaches a lower figure than $6.25 per ton, this fuel-oil will be able to

compete with it from an economic point of view as soon as a sufficiently large supply of it is guaranteed.

Some of the advantages claimed for liquid fuel are:

1. Diminished loss of heat up the funnel, owing to the clean condition the tubes can be kept in, and to the smaller amount of air which has to pass through the combustion-chamber for a given fuel consumption.

2. A more equal distribution of heat in the combustion-chamber, as the doors do not have to be opened, and consequently a higher efficiency is obtained.

3. With oil there is no chance of getting dirty fires on a hard run, as with coal.

4. A reduction in cost of handling fuel, since in one case it is all done mechanically or by gravitation, while with solid fuel a great deal of manual labor is required.

5. No firing tools or grate-bars are used, consequently the furnace lining and brickwork floors, etc., suffer less damage.

6. No dust nor ashes to cover or fill the tubes and diminish the heating surface, nor to be handled or carted away.

7. Petroleum does not suffer while being stored, while the deterioration of coal under atmospheric influence is well known.

8. Ease with which fire can be regulated, from a low to a most intense heat in a short time.

9. Absence of sulphur or other impurities and longer life of plates, etc.

10. Lessening of manual labor to fireman.

11. Great increase of steaming capacity, as was conclusively proved when many factories returned to coal in Pennsylvania and Ohio; they had to increase their boiler capacity about 35 per cent.

The coal consumption of the world is probably in the neighborhood of 600,000,000 tons per annum, while that of petroleum is only about 17,000,000 tons, of which by far the greatest part is used for illuminating or lubricating purposes; so the amount of petroleum available for fuel purposes is probably not more than 1 per cent of the coal used.* Liquid fuel will therefore never be used very ex-

* These figures are for 1899. In 1912, according to the reports of the U. S. Geological Survey, the total coal production of the United States alone was, in round figures, 716,920,000 tons of 2000 lbs., and that of petroleum, taking 330 lbs. as the weight of a barrel of 42 gallons, 36,650,000 tons, or a trifle over 5 per cent of the coal production.

tensively as compared with coal, but where it is used it will have many advantages over the solid fuel. On vessels of war, and especially torpedo-boats, it would give the very best results if used intelligently.

Calorific Values of California Fuel Oils.—R. W. Fenn, in *Engineering News*, May 13, 1909, gives the following table showing that the heating value of fuel oil has a direct relation to its density:

Deg. Baumé.	Specific Gravity	Weight per bbl.	B.T.U. per lb.	Thousands B.T.U. per bbl.	Deg. Baumé.	Specific Gravity.	Weight per bbl.	B.T.U. per lb.	Thousands B.T.U. per bbl.
10°	1.000	350	18,380	6442	28°	0.887	311	19,460	6051
11	0.993	348	18,440	6418	29	0.881	309	19,520	6030
12	0.986	346	18,500	6394	30	0.875	307	19,580	6008
13	0.979	343	18,560	6370	31	0.870	305	19,640	5990
14	0.972	341	18,620	6345	32	0.865	303	19,700	5973
15	0.966	339	18,680	6323	33	0.860	301	19,760	5954
16	0.959	336	18,740	6302	34	0.854	299	19,820	5935
17	0.953	334	18,800	6280	35	0.849	298	19,880	5917
18	0.947	332	18,860	6257	36	0.844	296	19,940	5901
19	0.940	330	18,920	6235	37	0.839	294	20,000	5885
20	0.934	327	18,980	6212	38	0.835	293	20,050	5865
21	0.928	325	19,040	6193	39	0.830	291	20,100	5846
22	0.922	323	19,100	6173	40	0.825	289	20,150	5827
23	0.916	321	19,160	6153	41	0.820	288	20,200	5808
24	0.910	319	19,220	6133	42	0.816	286	20,250	5789
25	0.905	317	19,280	6113	43	0.811	284	20,300	5770
26	0.899	315	19,340	6093	44	0.806	283	20,350	5751
27	0.893	313	19,400	6072	45	0.802	281	20,400	5732

From these figures it appears that the thinner the crude oil the higher is its heating value per pound but the less per barrel.

The following table shows the world's production for 1911 in

Country.	Rank.	Bbls.	Metric Tons.	Total %
United States	1	220,449,391	29,393,252	63.80
Russia	2	66,183,691	9,066,259	19.16
Mexico	3	14,051,643	1,873,552	4.07
Dutch East Indies	4	12,172,949	1,670,668	3.52
Roumania	5	11,101,878	1,544,072	3.21
Galicia	6	10,485,726	1,458,275	3.04
India	7	6,451,203	897,184	1.87
Japan	8	1,658,903	221,187	.48
Peru	9	1,398,036	186,405	.40
Germany	10	995,764	140,000	.29
Canada	11	291,096	38,813	.08
Italy	12	*71,905	10,000	.02
Other	..	* 200,000	26,667	.06
Total	....	345,512,185	46,526,334	100.00

*Estimated.

barrels and metric tons ("Mineral Resources," U. S. Geological Survey).

Properties of California Crude Oils.—(F. S. Wade, *Power*, Nov. 14, 1911.) A table is given showing a great variation in the density and heating value of oils obtained from different districts. The density ranges from 0.854 sp. gr. = 34 degrees Baumé = 7.12 lbs. per gallon to 0.988 sp. gr. = 11.7 Baumé = 8.24 lbs. per gal. The sulphur ranges from 0.32 to 4.43%, and the B.T.U. per lb. from 19,400 B.T.U. per lb. for the lightest oils down to 18,480 for the heaviest. These figures are for oil entirely free from moisture. The B.T.U. per pint of the lightest oil is 17,270, and that of the heaviest oil 19,030.

The variations in the calorific value of oils of apparently the same gravity are often found and are due to water in the oil, which in many cases is undetected and not corrected for on account of the rather general use of the so-called "gasolene test" for water. This test is made by mixing equal portions of gasolene and oil and allowing the mixture to stand 24 hours. At the end of this time the percentage of water can, supposedly, be read off on a scale at the bottom of the test cylinder. This test rarely with any oil, and almost never with the heavier oils, reveals the full and correct amount of water present. In the experience of the writer, water in crude oil can be determined satisfactorily only by the use of a high-speed centrifugal testing machine or by distillation.

It is often necessary to correct the gravity or volume of fuel oil for temperature. Repeated experiment has proved that the expansion factors of California oils between 12 and 22 degrees Baumé is substantially 0.0004 per degree Fahrenheit, which gives a correction in gravity of 0.06 degrees Baumé for each degree Fahrenheit of the oil above or below 60°.

The accompanying table (from *Power*) gives what may be considered representative figures for the composition, weights and heat values of American oils:

PROPERTIES OF CRUDE OILS.

Kind of Oil.	Composition by Weight.				Specific Gravity.	Pounds per Gallon.	B.T.U. per Pound.	
	Carbon.	Hydrogen.	Sulphur.	Oxygen.			By Test.	Computed.
Ohio	0.834	0.147	0.006	0.013	0.800	6.68	19,580	19,718
Pennsylvania, light	0.820	0.148	0.010	0.022	0.816	6.80	19,930	19,519
Pennsylvania, heavy	0.849	0.137	.....	0.014	0.886	7.40	19,210	19,385
West Virginia, light	0.843	0.141	0.003	0.013	0.841	7.02	18,400	18,527
West Virginia, heavy	0.835	0.133	0.008	0.024	0.873	7.28	18,324	18,860
Texas	0.840	0.132	0.010	0.018	0.925	7.71	19,100	18,928
California	0.852	0.124	0.005	0.019	0.959	8.00	18,500	18,656
Average	0.839	0.139	0.007	0.018	0.871	7.27	19,006	19,086

The formula by which the computed results were obtained is not given.

Other figures for the heating value of oils are given below:

Redondo, Cal., oil, six lots: Moisture, 1.82 to 2.70 per cent; sulphur, 2.17 to 2.60 per cent; B. T. U. per lb., 17,717 to 17,966. Kilowatt-hours generated per barrel (334 lbs.) of oil in a 5000 K. W. plant, using water-tube boilers, and reciprocating engines and generators having a combined efficiency of 90.2 to 94.75 per cent (boiler economy and steam-rate of engine not stated). 2000 K. W. load, 237.3; 3000 K. W., 256.7; 5000 K. W., 253.4; variable load, 24 hours, 243.8. (C. R. Weymouth, Trans. A. S. M. E., 1908.)

Beaumont, Texas, oil analyzed as follows (*Eng. News,* Jan. 30, 1902): C, 84.60; H, 10.90; S. 1.63; O, 2.87. Sp. gr., 0.92; flash point, 142° F.; burning point, 181° F.; heating value per lb., by oxygen calorimeter, 19,060 B. T. U. A test of a horizontal tubular boiler with this oil, by J. E. Denton gave an efficiency of 78.5 per cent. As high as 82 per cent has been reported for California oil.

Bakersfield, Cal., oil: Sp. gr. 16° Baumé; moisture, 1 per cent; sulphur, 0.5 per cent; B. T. U. per lb., 18,500.

The following table shows the relative values of petroleum and coal. It is based on the following assumed data: B. T. U. per lb. of oil 19,000; sp. gr., 0.90;=7.5 lbs. per gal.; 1 barrel=42 gals. = 315 lbs.

Coal, B.T.U. per lb.	1 lb. Coal = lbs. Oil.	1 bbl. Oil = lbs. Coal.	1 Ton Coal = bbl. Oil.
10,000	1.9	598	3.34
11,000	1.727	544	3.68
12,000	1.583	499	4.01
13,000	1.462	460	4.34
14,000	1.357	427	4.68
15,000	1.267	399	5.01

From this table we see that if coal of a heating value of only 10,000 B.T.U. per lb. costs $3.34 per ton, and coal of 14,000 B.T.U. per lb. $4.68 per ton, then the price of oil will have to be as low as $1 a barrel to compete with coal; or, if the poorer coal is $3.34 and the better coal $4.68 per ton, then oil will be the cheaper fuel if it is below $1 per barrel.

Specifications for fuel oil adopted by the Southern Pacific Railway system (1911) contain the following: It must contain no sand or foreign matter in the shape of sticks, waste, stones, etc., and must be sufficiently liquid to flow readily in 4-inch pipes at a tem-

perature of 70° F. It must contain as little water as possible, and oil containing more than 2 per cent of water and other impurities will not be accepted.

Fuel oil will not be accepted for general use, the flash point of which is less than 110° F. when tested in the open cup, Tagliabue method. The oil to be heated at rate of 5° per minute, and test flame applied every 5°, beginning at 90°. This flash point being the danger point at which the oil begins to give off inflammable gases, the fire or burning point is not required.

The specific gravity of fuel oil should range between 13° and 29° Baumé at 60° F.

Oil vs. Coal as Fuel.—A test by the Twin City Rapid Transit Company of Minneapolis and St. Paul showed that with the ordinary Lima oil weighing $6\frac{6}{10}$ pounds per gallon, and costing $2\frac{1}{4}$ cents per gallon, and coal that gave an evaporation of $7\frac{1}{2}$ lbs. of water per pound of coal, the two fuels were equally economical when the price of coal was $3.85 per ton of 2000 lbs. With the same coal at $2.00 per ton, the coal was 37 per cent more economical, and with the coal at $4.85 per ton, the coal was 20 per cent more expensive than the oil. These results include the difference in the cost of handling the coal, ashes, and oil.*

In 1892 there were reported to the Engineers' Club of Philadelphia some comparative figures, from tests undertaken to ascertain the relative value of coal, petroleum, and gas.

	Lbs. Water, from and at 212° F.
1 lb. anthracite coal evaporated	9.70
1 lb. bituminous coal	10.14
1 lb. fuel oil, 36° gravity	16.48
1 cubic foot gas, 20 C. P	1.28

The gas used was that obtained in the distillation of petroleum, having about the same fuel value as natural or coal-gas of equal candle power.

Taking the efficiency of bituminous coal as a basis, the calorific energy of petroleum is more than 60% greater than that of coal; whereas, theoretically, petroleum exceeds coal only about 45%—the one containing 14,500 heat-units, and the other 21,000.

* *Iron Age*, Nov. 2, 1893.

Comparative tests of crude petroleum and of Indiana block coal for steam-raising at the South Chicago Steel Works* showed that, with coal, 14 tubular boilers 16 ft. × 5 ft. required 25 men to operate them; with fuel oil, 6 men were required, a saving of 19 men at $2 per day, or $38 per day.

For one week's work 2731 barrels of oil were used, against 848 tons of coal required for the same work, showing 3.22 barrels of oil to be equivalent to 1 ton of coal. With oil at 60 cents per barrel and coal at $2.15 per ton, the relative cost of oil to coal is as $1.93 to $2.15. No evaporation tests were made.

Specifications for the Purchase of Fuel Oil.—The U. S. Bureau of Mines has, in Technical Paper No. 3, 1911, the following specifications, which were drawn up for the government, covering (1) the number of heat-units obtained for a given price, (2) the physical character of the oil, (3) flash and burning points, and (4) amounts of extraneous matter.

Fuel oil should be either a natural homogeneous oil or a homogeneous residue from a natural oil; if the latter, all constituents having a low flash point should have been removed by distillation; it should not be composed of a light oil and a heavy residue mixed in such proportions as to give the density desired.

It should not have been distilled at a temperature high enough to burn it, nor at a temperature so high that flecks of carbonaceous matter began to separate.

It should not flash below 60° C. (140° F.) in a closed Abel-Pensky or Pensky-Martens tester.

Its specific gravity should range from 0.85 to 0.96 at 15° C. (59° F.); the oil should be rejected if its specific gravity is above 0.97 at that temperature.

It should be mobile, free from solid or semi-solid bodies, and should flow readily, at ordinary atmospheric temperatures and under a head of 1 ft. of oil, through a 4-in. pipe 10 ft. in length.

It should not congeal nor become too sluggish to flow at 0° C. (32° F.).

It should have a calorific value of not less than 18,000 B.T.U. per lb.; 18,450 B.T.U. per lb. to be the standard. A bonus is to be paid or a penalty deducted according to the method stated under section 21, as the fuel oil delivered is above or below this standard.

It should be rejected if it contains more than 2% water.

It should be rejected if it contains more than 1% sulphur.

It should not contain more than a trace of sand, clay, or dirt.

* Trans. A. I. M. E., xvii. p. 807.

Viscosity of Oils at Different Temperatures. (E. H. Peabody, Proc. Soc. Naval Archts. & Marine Engrs., 1912.)—Figures approximated from plotted curves. Tests by Engler viscosimeter.

Temp. of oil, deg. F....	....	....	100	120	140	160	180	200	220	240
Beaumont,	Sp. Gr.	Flash Point.	Viscosity							
Tex., oil...	0.936	236° F.	5	3	2	1.2	1.0	0.8	—	—
California...	.962	282	23	13	6.5	3.6	2.1	1.5	1	—
" ...	.970	260	50	29	11.5	5.	2.9	1.8	1.2	—
" ...	.974	280	54	33	12.5	7.4	5.	3.6	2.7	2

With all ordinary oils heating to within 50° F. of the flash point is sufficient to render them suitable for use with mechanical burners. Many of the lighter oils are sufficiently limpid at ordinary temperatures to be used without heating.

Use of Heavy Oil.—Mexican crude oil is very sticky and viscous at 80° F. On heating to 212° it turned to foam owing to the presence of water which failed to separate out. Sp. gr. at 60°, 0.981, or 12.5 Baumé. Moisture and silt 3.5%; flash point 310°; burning point 347°; B.T.U. per lb. 17,551. Was successfully sprayed and burned under natural draft on being heated to 270° at a pressure of 165 lbs. The capacity fell off about 40% from that obtained with the same apparatus with oil of 18° Baumé.

Tar as Fuel.*—Under normal conditions coal tar has a value for other purposes exceeding its fuel value considerably; but this is not always true, and it is seldom that what is ordinarily called water-gas tar can be disposed of at a price near its fuel value.

The yield of coal tar produced by the distillation of coal varies, according to the coal and the method employed, from 4.5 to 6.5 per cent of the weight of coal. Its specific gravity is about 1.25, a gallon weighing 10.3 lbs. The ultimate analysis of a tar made from a standard gas coal, in a medium-sized gas works, is as follows:

Carbon, 89.21; hydrogen, 4.95; nitrogen, 1.05; oxygen, 4.23; ash, trace; volatile sulphur, 0.56. Heating value by Dulong's formula, 15,781 B. T. U. per lb. A series of tests in a bomb calorimeter gave 15,708 British thermal units, the tar being practically freed from water.

Gas-works Residuals as Fuel.—The value of coke, coke breeze, coal-tar and water-gas tar as fuel for steam boilers is discussed by

* C. F. Pritchard, in *The Engineer* (Chicago), April 1, 1903.

C. F. Pritchard, (*Power*, May, 1902). A coke made from a standard gas coal analyzed as follows: Moisture 1.12; volatile matter 3.38; ash 8.75; fixed carbon 86.75; sulphur 0.84, B.T.U. per lb. calculated 13,341; by calorimeter 13,469 per lb.; coke, 14,944 per lb. combustible. Monthly records of water evaporated by coke and by Cumberland, Md., semi-bituminous coal showed that the coke was practically of the same value per pound as the coal, the evaporation from and at 212° per lb. of fuel ranging from 8.7 to 11.1 lbs., the lower figure being obtained both with coal alone and with coke used to replace more than half of the coal. The higher figure was obtained in a month when the relative proportions of coal and coke were about as 4 to 3. A test with coke alone gave an evaporation of 10.39 lbs. from and at 212° per pound of coke. The best method of burning coke was found to be using a deep furnace, with the grate bars at the ground level and carrying a bed of coke 2½ to 3 ft. thick. Heated air for burning the gas made from the coke was furnished through a hollow bridge wall. Tests were made with one-fifth of coke breeze added to the coke, and also with coke breeze added to coal in various proportions, and after deducting the evaporation credited to the coal (9.25 lbs.) the evaporation due to the addition of breeze was found to range from 5.3 to 7.1 lbs. from and at 212° per lb. of breeze.

Coal tar of a heating value of 15,708 B.T.U. per lb. was tested with results ranging from 11.07 to 12.22 lbs. from and at 212° per lb. of tar. It is believed that much better results could be obtained under more favorable conditions. Water-gas tar made from gas oil was also tested. Its analysis was C, 92.70; H, 6.13; N, 0.11; O, 0.69; ash, trace; volatile S, 0.37; specific gravity 1.15; heating value by calorimeter, 17,193 B.T.U. per lb. Eleven tests gave results ranging from 13.08 to 16.20 lbs. from and at 212° per lb. tar, averaging 14.9 lbs. Mr. Prichard concludes that taking steam coal at $3.75 per ton of 2000 lbs. a fair market value for coke would be $3.75; coke breeze, per ton, $2.48; coal-gas tar and water-gas tar, per barrel of 50 gallons, respectively $1.38 and $1.39.

Gas Fuel.—Natural gas is an ideal fuel for steam-boilers wherever it can be obtained in sufficient quantity and at reasonable cost as compared with coal. About 1890 it was in quite general use in western Pennsylvania and in many places in Ohio and Indiana, when numerous wells furnished vast quantities of gas at a high pressure, but in a few years the supply diminished and it became too high in price to be commonly used in steam-boilers. Its use is now confined chiefly to household purposes. The following are some analyses:*

* *Engineering and Mining Journal*, April 21, 1894.

NATURAL GAS IN OHIO AND INDIANA.

Description.	Ohio.			Indiana.			
	Fostoria.	Findlay.	St. Mary's	Muncie.	Anderson.	Kokomo.	Marion.
Hydrogen	1.89	1.64	1.94	2.35	1.86	1.42	1.20
Marsh-gas	92.84	93.35	93.85	92.67	93.07	94.16	93.57
Olefiant gas	.20	.35	.20	.25	.47	.30	.15
Carbon monoxide	.55	.41	.44	.45	.73	.55	.60
Carbon dioxide	.20	.25	.23	.25	.26	.29	.30
Oxygen	.35	.39	.35	.35	.42	.30	.55
Nitrogen	3.82	3.41	2.98	3.53	3.02	2.80	3.42
Hydrogen sulphide	.15	.20	.21	.15	.15	.18	.20

Approximately 30,000 cubic feet of gas has the heating power of one ton of coal.

The following analyses are given by J. M. Whitham in Trans. A. S. M. E., 1905:

NATURAL GAS IN PENNSYLVANIA AND WEST VIRGINIA

Illuminants	0.45	0.15	0.50	1.6
Carbonic oxide	0.00	0.00	0.15	1.8
Hydrogen	0.20	0.30	0.25	0.3
Marsh gas	81.05	83.20	83.40	81.9
Ethane	17.60	15.55	15.40	13.2
Carbonic acid	0.00	0.20	0.00	0.0
Oxygen	0.15	0.10	0.00	0.4
Nitrogen	0.55	0.50	0.30	0.8
B.T.U. per cu. ft. at 60° F. and 14.7 barometer	1030	1020	1026	1098

The first three analyses are of gas from nine wells in Lewis Co., W. Va., the last is from a mixture from fields in three States supplying Pittsburgh, Pa.

Producer-gas.—Since the invention of the Siemens producer and regenerative furnace, in 1856, and their general introduction into metallurgical and glass works, many attempts have been made to use producer-gas as a fuel for steam-boilers, the evident advantage being the ease of conveying the gas in pipes from a centrally-located producer-plant to a number of boilers, the facility of operation of the boilers with gaseous fuel, and the saving of labor. These attempts have generally failed, however, on account of the facts that the gas-making process always entailed some loss of heat, that the producers were of too great cost, and that it was difficult to drive them at the varying rates usually required in steam-boiler practice. The following analysis of producer-gas is given by W. H. Blauvelt:*

* Trans. A. I. M. E., xviii. p. 614.

PRODUCER-GAS FROM ONE TON OF COAL.

Analysis by Volume.	Per Cent.	Cubic Feet.	Pounds.	Equal to
CO	25.3	33,213.84	2451.20	1050.51 lbs. C + 1400.7 lbs. O.
H	9.2	12,077.76	63.56	63.56 " H.
CH_4	3.1	4,069.68	174.66	174.66 " CH_4.
C_2H_4	0.8	1,050.24	77.78	77.78 " C_2H_4.
CO	3.4	4,463.52	519.02	141.54 " C + 377.44 lbs. O.
N (by difference	58.2	76,404.96	5659.63	7350.17 " Air.
	100.0	131,280.00	8945.85	

Calculated upon this basis, the 131,280 ft. of gas from the ton of coal contained 20,311,162 B.T.U., or 155 B.T.U. per cubic foot, or 2270 B.T.U. per lb.

The composition of the coal from which this gas was made was as follows: Water, 1.26% ; volatile matter, 36.22% ; fixed carbon, 57,98% ; sulphur, 0.70% ; ash, 3.78%. One ton contains 1159.6 lbs. carbon and 724.4 lbs. volatile combustible, the energy of which is 31,302,200 B.T.U. Hence, in the processes of gasification and purification there was a loss of 35.2% of the energy of the coal.

The following table of comparative analyses and heating values of different kinds of gas is given by W. J. Taylor:*

	Natural Gas.	Coal-gas.	Water-gas.	Producer-gas.	
				Anthra.	Bitumin.
CO	0.50	6.0	45.0	27.0	27.0
H	2.18	46.0	45.0	12.0	12.0
CH_4	92.6	40.0	2.0	1.2	2.5
C_2H_4	0.31	4.0	....	....	0.4
CO_2	0.26	0.5	4.0	2.5	2.5
N	3.61	1.5	2.0	57.0	56.2
O	0.34	0.5	0.5	0.3	0.3
Vapor	.....	1.5	1.5	....	....
Pounds in 1000 cubic feet	45.6	32.0	45.6	65.6	65.9
Heat-units in 1000 cubic feet	1,100,000	735,000	322,000	137,455	156,917

Corn as Fuel.—It was once common in Nebraska, in years when the corn crop was abundant and selling prices low, to use corn instead of coal as fuel. Prof. C. R. Richards reports in *Cassier's Magazine* the results of two boiler tests, one with corn and one with good Rock

* Trans. A. I. M. E., xviii. p. 205.

Springs bituminous coal, costing in Lincoln, Neb., $6.65 per ton. The results showed that the coal gave 1.9 times as much heat per lb. as the corn. Tests of both fuels in a fuel calorimeter gave 7076 B.T.U. for the corn, and 13,010 for the coal, a ratio of 1 to 1.86. Other calorimeter tests of different sample of corn gave results as follows:

THE HEATING VALUE OF CORN.

Kind of Material.	Heating Value in B.T.U.		
	Per lb. of Material.	Per lb. of Dry Material.	Per lb. of Dry Combustible.
Yellow Dent corn and cob	8040	....	....
Yellow Dent corn	8202	8959	9085
Yellow Dent cob	7214	7841	7958
White Dent corn and cob	7841	....	....
White Dent corn	8382	9199	9301
White Dent cob	7571	8174	8285

Assuming the average heating value of Nebraska coal at 11,500 B.T.U. per lb., that of corn 8040 B.T.U., and the weight of corn 56 lbs. per bushel, corn at 10 cents per bushel would be as cheap a fuel as coal at $5.11 per ton of 2000 lbs.

CHAPTER VII.

FURNACES.—METHODS OF FIRING.—SMOKE-PREVENTION.—MECHANICAL STOKERS.—FORCED DRAFT.

Location of the Furnace.—The furnace, or fire-box, of a steam-boiler should be considered as an apparatus separate and distinct from the boiler itself. The function of the furnace is to generate heat by the combustion of the fuel; that of the boiler is to transfer the heat into the water. The combustion-chamber, when there is one, is an extension of the fire-box; its office is to afford space in which to complete the combustion of the volatile gases which are imperfectly burned in the fire-box.

In internally fired boilers, such as the locomotive, marine, Lancashire, and vertical tubular boilers, the fire-box is located inside of the boiler. The chief advantage of this method of construction is its economizing of space, but it is attended with the disadvantages of limiting the area of grate-surface, and thereby limiting the coal-burning capacity of the boiler, and, with soft coal, of providing insufficient space for a combustion-chamber, in which to burn the volatile gases. Another objection to the internal furnace is usually that the walls of the fire-box and combustion-chamber are metallic surfaces, kept comparatively cool by the water in the boiler, which chill the gases and tend to prevent their combustion. In some such furnaces, however, fire-brick arches or walls are used, which have the beneficial effect of keeping the furnace at a high tmperature.

With other types of boilers, such as the horizontal tubular and the common form of water-tube boiler, with inclined tubes, it is customary to locate the furnace immediately underneath the boiler, between the brick walls of the setting. For horizontal tubular boilers this method of setting is usually satisfactory, for the width between the side-walls of the setting is sufficient to accommodate an ample area of grate-surface, on which may be burned, at moderate rates of combustion, all the coal that should be burned for the amount of heating surface of the boiler. When soft coal is used this setting allows

of a long travel of the gases, which is favorable to their combustion, and furthermore, it furnishes sufficient space in which to build fire-brick arches, baffle-walls, or other devices to more perfectly secure complete combustion.

With water-tube boilers of the inclined-tube form, this location is unobjectionable when large sizes of anthracite coal are used; in this case the grate-surface is sufficiently large to burn with moderate draft all the coal that is required to develop the full economical capacity of the boiler, and the small quantity of volatile gases is easily burned in the fire-box. With small sizes of coal this setting does not provide sufficient space for grate-surface enough to develop the usual rated capacity of the boiler, unless a very strong draft is provided either by a tall chimney or by mechanical means. The fine sizes of anthracite usually contain a considerable percentage of moisture, which forms combustible gas by its decomposition by red-hot carbon, some of which gas is apt to escape unburned unless abundant room is provided for burning it in the fire-box.

For bituminous coal the ordinary setting of an inclined water-tube boiler, with the air-passages rising immediately above the furnace into the nest of tubes above, is entirely unsuitable. There is insufficient room in the furnace for the burning of the gases; they are chilled by the water-tubes above the furnace; they deposit soot upon them, diminishing the effectiveness of the heating surface, and a large proportion of the gas escapes unburned. A furnace which provides a long travel of the gases under a fire-brick roof, before they are allowed to enter the nest of tubes, such as the setting of the Heine boiler, is an improvement in this respect, but such a furnace is not well adapted to boilers having more than seven horizontal rows of tubes, unless transverse baffle walls are built in the air passage along the tubes (or a longitudinal baffle made of tiles carried on one of the horizontal rows of tubes near the middle of the bank), otherwise the passage is of too large an area in cross-section to cause the current of hot gas to completely envelop all the tubes, and it therefore allows of "short-circuiting," rendering some of the heating surface ineffective.

External fire-brick furnaces, commonly called "Dutch ovens," are used with the vertical types of water-tube boilers, and to some extent with the inclined-tube boilers, with great advantage. When properly designed they admit of sufficient areas of grate-surface, and of the use of deflecting arches, baffle-walls, etc., for insuring combustion of the gases.

Requirements of a Good Furnace.—(1) It should have ample coal-burning capacity. It should be able to burn the amount of coal needed to generate the maximum quantity of steam that may be required during any hour of the day, under the most unfavorable conditions that may be expected, such as atmospheric or other conditions tending to diminish the chimney draft, and coal of a poorer quality than is usually furnished.

(2) The grates should be of such a kind that ash and clinker may be easily removed from them without stopping the operation of the boiler for more than a few minutes at a time, and the bars should be so spaced that coal is not apt to be wasted by falling through them.

(3) It should be so constructed as to be capable of burning thoroughly all the gases that may be distilled from the fuel before they come in contact with the comparatively cool heating surfaces of the boiler. This means a large combustion chamber and provision for mixing the combustible gases with the air supply.

(4) It should be durable, free from breakdowns of coal-feeding appliances or shaking grates, and from melting down of fire-brick arches.

(5) Furnaces of externally fired boilers should be built with thick walls, so as to minimize as far as possible loss of heat by radiation, or preferably with double walls with air-spaces between. The air-spaces may with advantage be so arranged as to cause a current of air to flow through them into the ash-pit or above the fire.

Burning of Anthracite Coal.—For large sizes of anthracite, such as egg, almost any kind of furnace is suitable, and no great degree of skill is needed to fire the coal so as to obtain the best results. With all ordinary proportions of grate and heating surface a moderate draft suffices to burn enough coal to drive the boiler up to and beyond its economical rating. Hand-firing is generally used with this coal, and all that the fireman needs to do is to keep the bed of coal level and of a depth proportionate to the force of the draft, to watch carefully to prevent the formation of air-holes in the bed of coal, and to clean the fire at long intervals of time, say from six to ten hours. When there is plenty of draft the fireman has control of two factors governing the combustion, viz., the damper and the thickness of the bed of coal, which he can regulate at his pleasure. With a given force of draft, which may be controlled by the damper, if the bed of coal is too thin an excessive supply of air passes through it, causing a waste of heat in the chimney gases; if it is too thick some of the carbon

will be burned only to carbon monoxide, instead of to carbon dioxide, causing a great loss of heat. The latter source of loss, when there is sufficient draft available, may easily be prevented, for it makes itself known by a sluggish action of the fire, the presence of blue flames on the bed of coal, and low temperature of the furnace. The remedy is either to carry a thinner bed of fire, or to open the damper and give a stronger draft in the furnace. The loss due to excess of air on account of too thin a bed of coal is much more common, and its effect in the furnace is not so apparent to the fireman. It may be prevented by carrying as thick a bed of coal as will not cause the temperature of the furnace to be visibly lowered and blue flames to make their appearance.

In all cases the highest possible temperature of the furnace gives the highest economy, provided the heating surface is of sufficient extent to absorb the proper proportion of the heat generated, and to cool the gases to the lowest practicable temperature before they reach the chimney-flue. The highest temperature is obtained by firing small quantities of coal at a time and by keeping the bed of coal at such a thickness as will insure complete combustion without an excessive supply of air passing through it.

With small sizes of anthracite there is more difficulty in securing the best conditions of combustion.. The fineness of the coal tends to choke the air-passages through the bed on the grate, and a thinner bed has therefore to be carried unless there is a very strong draft, and a thin bed is more difficult than a thick one to keep free of air-holes. The coal is usually much higher in ash than large-sized coal, and the fires therefore need to be cleaned oftener—an operation which always chills the fire, decreasing the rate of steaming, and causes a waste of heat. The evaporation per pound of combustible with fine sizes of coal is usually in ordinary practice considerably less than with egg coal.

In order to burn a sufficient quantity of fine sizes of anthracite coal to develop the required capacity of a boiler it is common to use a forced blast provided either by a fan or by a steam-jet.

Burning Small Sizes of Anthracite.—The report of the Pennsylvania State Commission on "Waste of Coal Mining," 1883, contains the following:

A number of experiments were made in the testing laboratory of Coxe Bros. & Co., by Mr. John R. Wagner, in burning small coals

with a forced draft, obtained in one case by a fan and in the other by a steam-jet. They showed:

"*First.*—That the ashes produced by a steam-jet were never as low in carbon as those produced by the fan; that is, an appreciably larger per cent of the carbon was utilized by the fan-blast. This appears to be due to the fact that when the carbon in the ash over the grate is reduced to a certain point the steam dampens it somewhat, and it ceases to burn sooner than it does when dry air only is blown through it.

"*Second.*—That with the fan-blast the rate of combustion per square foot per hour is greater than with the steam-jet.

"*Third.*—It was found that where a bed of coal was ignited and burned out, the percentage of carbon in the ash is much less than where coal is successively added to the burning mass. In practice it is not generally possible to allow the bed to burn out sufficiently before adding the cold, unignited coal; the result is a damping down of the fire, which causes the ash to cease burning sooner than it would do if there were no reduction of temperature and checking of the draft due to the adding of the coal.

"*Fourth.*—There seems to be no doubt that the introduction of steam into the ash-pit decreases very materially the tendency of the coal to clinker on the grate in comparison with the fan-blast or natural draft. It also changes the color, volume, and character of the flame, and, owing to producer action, increases the distance that the flame extends beyond the bridge-wall. In many cases it is not practicable or at least it is very difficult, to fire the smaller sizes of coal without the steam-jet on account of the clinkering. This effect of steam on clinkering is probably due to the fact that the steam, to a certain extent, moistens the ash close to the grate and prevents the ash from reaching there at as high a temperature as it would with dry air. It is also probable that the decomposition of the steam into carbonic oxide and hydrogen, which takes place to a certain extent, and which, of course, is accompanied by a reduction of temperature, tends to prevent clinkering. The decomposition of the steam, accompanied by the formation of carbonic oxide and hydrogen, will probably account for the difference in the flame referred to.

"*Fifth.*—A careful study of the burning of culm, that is, the burning of small coals with more or less dust in them, in these and other experiments, seemed to show that in almost all cases it is accompanied by a very high percentage of carbon in the ash, which analysis showed, in some cases, reached 58 per cent. Unless special precautions are taken to prevent it, a large portion of the fine coal runs down through the grate. When the culm gets red hot it acts almost like dry sand and works its way into the ash-pit, thus increasing largely the percentage of carbon. Where coal has to be transported any distance, the value of the culm at the mines being very

small, it is probable from the investigations made, that it would be cheaper to remove the dust and transport only the larger coal.*

"*Sixth.*—It has been found that the percentage of iron pyrites, which occurs to a greater or less extent in all coals, increases very rapidly with the smallness of the coal. This is due to the fact that the iron pyrites occur generally in thin layers or in incrustations on the coal. These thin layers are broken off and pulverized in the preparation and handling of the coal, and are therefore found to a much greater extent in the very small coal. It is, of course, well known that the presence of iron pyrites in fuel is very undesirable, as it generates sulphurous acid and has a tendency to destroy the grates or other iron-work around the boilers, besides, in many cases, increasing the tendency to clinker.

"*Seventh.*—That while the fan-blast produces the best ash and gives a more perfect and greater rate of combustion, yet in many cases it is more advantageous to use the steam-blower on account of the clinkering, which may cause very serious trouble. In certain localities, particularly in cities, the noise of the steam-blower is sometimes a disadvantage.

"*Eighth.*—While it is not positively demonstrated, it is thought that the question of mixing small coals from different veins of different localities is a matter of importance. It would appear that sometimes two coals, each of which, when burned separately, give reasonably satisfactory results, when mixed together, clinker and give trouble, probably because the ash of the combined coals forms a much more fusible silicate than either of the ashes separately.

"*Ninth.*—It would seem that the combustion of the small anthracite is more perfect when the coal remains undisturbed, or as nearly as possible in the condition in which it was put in the fire, instead of being turned over so that the partially consumed and the unconsumed coal are mixed together."

Comparative Efficiency of Steam- and Fan-blowers.—The following record of comparative tests of steam- and fan-blowers, made on three plain cylinder boilers at the Short Mountain Colliery, Lykens, Pa., was published in the *Colliery Engineer,* August, 1897. The conditions in each case were the same, rice coal being used as fuel on a sectional grate with 12 per cent air-openings.

The fan-blower consisted of a gangway-fan 33 in. diam., 4 paddles $9 \times 9\frac{1}{2}$ in., driven by a small slide-valve engine with cylinder $4\frac{1}{16}$ in

* This is now common practice. The old culm beds at the anthracite mines, which were formerly valueless, are rapidly being removed, their contents being passed through washing apparatus to remove the dirt and fine coal, and the remainder sorted into sizes by means of screens.

Dimensions of boilers.........36 in. diam., 42 ft. long. Area grate-surface, 3 boilers....61.5 sq. ft.	With Steam-blower.	With Fan-blower
Coal.		
Total coal burned (less moisture)	7,700 lb.	6,100 lb.
" ash	1,330 "	1,027 "
" combustible	6,370 "	5,073 "
Per cent of ash	17.2 per cent	16.8 per cent
Coal burned per hour	962.5 lb.	762.5 lb.
Combustible burned per hour	796.3 "	634.1 "
Water.		
Total water evaporated, actual conditions	39,241 lb.	34,890 lb.
Equivalent water evaporated per hour from and at 212°	5,444 "	4,867 "
Water evaporated per hour per lb. of coal, actual conditions	5.10 "	5.59 "
" " " " " " coal from and at 212°	5.66 "	6.38 "
" " " " " " combustible from and at 212°	6.84 "	7.67 "
H.P. developed	157.81 "	141.1 "
Average boiler pressure	77 "	78 "
Average temperature of feed-water	134°	137°
Blowers.		
Boiler H.P. used by blowers per hour from and at 212°	11.9 H.P.	5.64 H.P.
Per cent of the developed H.P. of the three boilers used for blowers	7.4 per cent	4 per cent
Cubic feet of air per minute	2,502 ft.	3,506 ft.
Average water-gauge	0.44 in.	0.52 in.
Horse-power in air	0.173 H.P.	0.28 H.P.

Remarks.—In the test with the fan-blower, the exhaust from the fan-engine was turned into the air-current and found sufficient to keep the grates free from clinker.

Average steam-pressure at steam-blowers	74 lb.
" I.H.P. of fan-engine	1.62 H.P.
" No. of revolutions of fan-engine	160 revs.
" " " fan	915 "
Useful effect of fan	17%

diam., 7¾ in. stroke. Steam was supplied by a small upright boiler on which an evaporative test was run during the test on the cylinder boilers.

The steam blower was made of ¾-in. pipe, circle 6¾ in. diam., 16 holes, tapered $\frac{1}{8}$ in. outside, $\frac{1}{16}$ in. inside, diam. Steam was supplied by the upright boiler on which a test was run as above. Duration of each test, 8 hours.

The saving of fuel by the use of the fan-blower, as compared with the steam-blower, was 13.9 per cent, taking into account the steam used by each blower.

Grate-bars.—Two styles of grate-bars in common use are shown in Figs. 11 and 12. The first is a plain cast-iron bar, tapered in cross-section, so as to make a wider opening between the bars at the lower than at the upper edge. Projections are cast on the sides of the bars to keep them at the proper distance apart. The second is channel-shaped in cross-section, with the upper surface provided with V-shaped openings. The total area of the air-spaces is usually made from 30 to 50 per cent of the total area of the grate-surface. The

width of the air-spaces and of the bars or ribs differs according to the size and kind of coal used. For fine sizes of anthracite the spaces are made as narrow as $\frac{3}{8}$ inch. For large sizes of anthracite

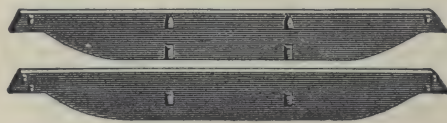

FIG. 11.—PLAIN GRATE BARS.

and for "run-of-mine" soft coal they are often made as wide as 1 inch. When the ash of the coal tends to form clinkers, narrow air-spaces are objectionable, as they are apt to become clogged, and are difficult

FIG. 12.—"HERRING-BONE" GRATE BAR.

to keep open so as to allow a sufficient supply of air to pass through them.

The resistance to the passage of air through the grate and the bed of coal lying upon it depends upon other things besides the size of the air-spaces in the grate, such as the size of the coal, its quality as regards coking or non-coking, the thickness of the bed of coal and ashes, the presence or absence of clinker, etc. With coals that are low in ash, and the ash non-clinkering, it is possible to burn the coal with very narrow air-spaces through the grates.

Fine sizes of anthracite are sometimes burned on flat cast-iron plates perforated with tapering holes about $\frac{1}{2}$ inch diameter at the upper surface, the total air-space being about 25 per cent of the grate-area.

Mr. F. A. Scheffler* reports a test in which grate-bars of the form shown in Fig. 12 were used, with the air-spaces only about $\frac{1}{8}$ inch wide, and the total area of air-space only about 15 per cent of the grate-surface. The coal was Pittsburg run-of-mine. With a draft

* Trans. A. S. M. E., vol. xv. p. 503.

pressure of 0.46 in water column, the rate of combustion was 24.8 lbs. of coal per sq. ft. of grate per hour, a rate sufficient to drive the boiler to much above its rated capacity.

On the other hand, the author once made a test with Illinois coal containing a large percentage of sulphur, with bars of the same type, the air-spaces being ½ inch in width and with a draft of 0.4 to 0.5 inch, but was unable to maintain, even with the maximum draft, a rate of combustion sufficient to develop the rated capacity of the boiler. In this case the ash fused into a glass, which ran into and choked the air-spaces.

Shaking- and Dumping-grates.—With coals of the character just described, shaking- or dumping-grates are almost a necessity, unless mechanical stokers are used in preference. Many different forms of such grates are in the market. They may be divided into three general classes: (1) Shaking- or Rocking-grates; (2) Dumping-grates; (3) Shaking- and Dumping-grates. In the first class the bars are usually divided into small sections, which, by means of rocking-bars and levers, are given an oscillatory or reciprocating motion, which causes the ash to fall through between the sections. In the second class the sections are made larger, and when the fires are to be cleaned from clinker the sections, or a part of them, such as those covering one-quarter of the whole grate-area, are rocked from a horizontal into a vertical position, thus breaking up the clinker and allowing it to fall through the large openings thus made. In the third class the sections are provided with mechanism by which either the shaking or the dumping motion may be given at will. For non-clinkering coals the first and third classes are used, and for clinkering coals the second and third.

The use of shaking-grates usually entails a loss of some unburned coal through the grates, amounting, with the most careful handling, to from 1 to 3 per cent of the total coal used; but this loss is often more than offset by the gain due to the more complete combustion which is obtained when the air-supply is unrestricted by ash and clinker.

Furnace for Burning No. 3 Buckwheat Coal.—Fig. 13 shows a longitudinal section of a furnace used with Babcock & Wilcox boilers in the power station of the Hudson & Manhattan R. R., Jersey City, N. J. (*Power,* Jan. 17, 1911). The peculiar features of this furnace are the unusual length of grate surface, 10 ft. from dead plate to bridgewall, and the three fire-brick arches in the combustion chamber.

Fine sizes of anthracite are apt to contain a great deal of moisture, which decomposes when fired on a white hot bed of coal, making water-gas, and in order to burn this gas before it becomes chilled by contact with the boiler tubes it is of advantage to provide a hot fire-brick surface for it to impinge against; hence these arches. The ash and refuse in this coal runs from 20 to 30 per cent, and it is therefore necessary to have shaking and dumping grates. The method of handling the fire is thus described: Each furnace is 9 ft. 6 in. wide, with three sections of grates and three fire doors.

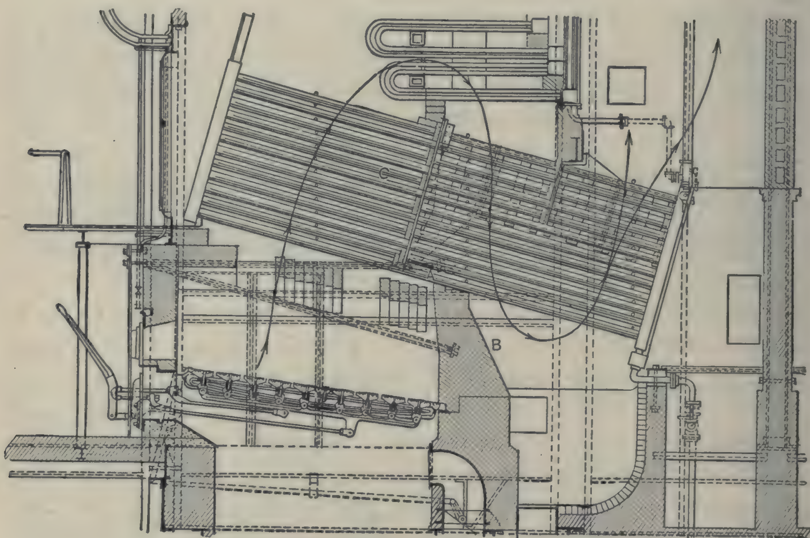

FIG. 13.—FURNACE FOR BURNING BUCKWHEAT COAL.

When the fire is to be cleaned, the unconsumed fuel is pushed back onto the back half of the grate and the front half is dumped, after which the live coal is pulled forward onto the clean part and the rear section dumped. All of the unconsumed fuel is then distributed over the entire grate and fresh fuel added, all of which may be accomplished in less than two minutes. This is done separately for each furnace. Starting thus with perhaps 2 ins. of live coal, the fires are allowed to build up until in the course of 6 to 7 hours they will have attained a thickness of some 12 or 14 ins., two-thirds of which will be ash and only the top part live coal. The cleaning is done between the peaks of the load. The air pressure used is from $\frac{1}{2}$ to $\frac{5}{8}$

in. of water in the ashpit with a light load, and with $\frac{1}{8}$ in. suction in the furnace. After the fire gets to be 4 or 5 ins. thick it is blown with about 2 ins. of pressure in the ashpit, which gives a balanced condition in the furnace. When the fire is at its thickest a blast of $2\frac{1}{2}$ ins. is used. The average rate of combustion is 25 lbs. per sq. ft. of grate and the maximum 36 lbs.

A 24-hour test, divided into three watches of 8 hours each, gave the following results:

		1	2	3	Average.
Evap. from and at 212° per sq. ft. h. s. per hr.	Lbs.	4.46	4.17	3.16	3.93
Evap. from and at 212° per lb. combustible	"	9.91	11.55	11.06	10.84
Efficiency, based on 14,900 B.T.U. per lb. combustible..........................	Per cent	64.6	75.2	72.1	70.1

Furnaces 12 ft. in length, designed by Hosea Webster, of the Babcock & Wilcox Co., were used satisfactorily for some years in the Waterside Station of the New York Edison Co., with No. 3 buckwheat coal. They were replaced by mechanical stokers burning semi-bituminous coal in order to obtain greater capacity from the boilers.

The McClave Grate is shown in Fig. 14. The rear section is shown in the usual position. The front section is shown with the bars tilted up for breaking the clinker.

Each row or section of grate-bars is divided into a front and rear series by means of two separate connecting-bars, operated by twin stub-levers and connecting-rods, with an operating handle adapted to grasp either one or both of the levers in such a manner that the front and rear series may be operated separately or together. This provides for cleaning out the worst kind of clinkers without wasting the unconsumed fuel on the surface, as that may be shoved over on the stationary part while the clinkers and ashes of the other series are being cut through into the ash-pit.

The McClave grate is extensively used for burning buckwheat, birdseye, and other fine sizes of anthracite coal. It is also used in the coal regions for burning culm or the refuse of the mines. Concerning the use of culm as fuel the circular of the manufacturers of the McClave grate says:

"In the anthracite coal-fields the waste product of the mines, commonly called culm, has proved to be a most excellent fuel for

steam purposes and is now being successfully used by the largest manufacturers and producers in the coal region. The cost of this fuel at the mines is merely nominal, but in order to burn it successfully it should contain at least 50 per cent of buckwheat and should be fresh

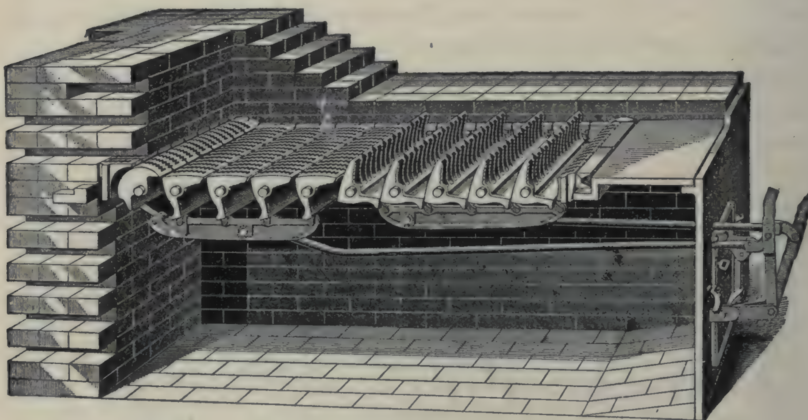

FIG. 14.—THE McCLAVE GRATE.

from the mine, for when the buckwheat is nearly all screened out of it, or when it has been exposed to the weather for any considerable length of time, it is comparatively worthless as fuel. Again, it will not pay to ship it any great distance, as the freight on culm is just as

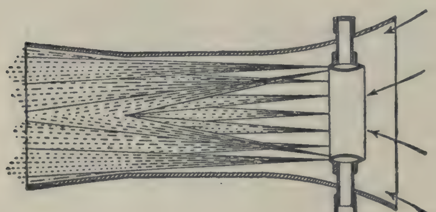

FIG. 15.—THE ARGAND BLOWER.

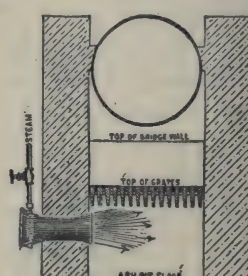

FIG. 16.

much per ton as it is on buckwheat coal, which, for steam purposes, is a much better fuel than culm, and costs at the mine only from 30 to 35 cents per ton more than culm."

The Argand Steam-blower, shown in Figs. 15 and 16, is commonly used in connection with the McClave grate. It delivers a large

volume of air, mixed with steam, under the grate. The steam is delivered to the blower through a metal ring, perforated with small holes on the edge nearest to the ash-pit. The jets of steam induce a strong current of air which is blown under the grate. While the use of a steam-jet is usually the most wasteful method of producing draft, it has certain advantages over a dry-air blast for the burning of cheap coals high in ash. The decomposition of the steam into oxygen and hydrogen by the hot carbon in the bed of coal is a cooling process, which tends to prevent the formation of clinker on the grates. The heat absorbed by this decomposition is again generated when the gases are burned in the fire-chamber above the grate, so that the only losses due to the use of steam are the cost of the steam itself and the heat required to superheat it to the temperature of the chimney gases.

How to Burn Soft Coal.—Of all known methods of burning soft coal the worst is the one which is most commonly practiced, viz., that of burning it in a common furnace, consisting of a set of grate-bars and a space of contracted dimensions between them and the heating surface of the boiler, the coal being fed by hand. This method is suitable for anthracite coal, the smaller sizes containing much surface moisture perhaps excepted, but when used for bituminous coal it is objectionable both on account of smoke and on account of loss of economy. The objections to the method increase the farther we go west from the anthracite coal-fields of Pennsylvania, being least with the semi-bituminous coals of Pennsylvania, Maryland, and Virginia, and increasing as we go westward and find the percentages of moisture and of volatile matter both increasing.

Objections to the Common Method.—The reasons for the difficulty in obtaining high economy from the bituminous coals when hand-fired in ordinary furnaces may perhaps be understood if we consider the sequence of events that take place between two consecutive firings, at an interval of, say, five minutes apart. Suppose that just before firing fresh coal an intensely hot bed of coke, say 6 inches deep, is lying upon the grate-bars. Half a dozen shovelfuls of coal, much of it of fine size, are spread evenly over the bed. The first thing that the fine fresh coal does is to choke the air-spaces existing through the bed of coke, thus shutting off the air-supply which is needed to burn the gases produced from the fresh coal. The next thing is a very rapid evaporation of moisture from the coal, a chilling process, which robs the furnace of heat. Next is the formation of water-gas by the chemical reaction, $C + H_2O = CO + 2H$, the steam being decomposed,

its oxygen burning the carbon of the coal to carbonic oxide, and the hydrogen being liberated. This reaction takes place when steam is brought in contact with highly heated carbon. This also is a chilling process, absorbing heat from the furnaces. The two valuable fuel-gases thus generated would give back all the heat absorbed in their formation if they could be burned, but there is not enough air in the furnace to burn them. Admitting extra air through the fire-door at this time will be of no service, for the gases being comparatively cool cannot be burned unless the air is highly heated. After all the moisture has been driven off from the coal, the distillation of hydrocarbons begins, and a considerable portion of them escapes unburned, owing to the deficiency of hot air, and to their being chilled by the relatively cool heating surfaces of the boiler. During all this time great volumes of smoke are escaping from the chimney, together with unburned hydrogen, hydrocarbons, and carbonic oxide, all fuel-gases, while at the same time soot is being deposited on the heating surface, diminishing its efficiency in transmitting heat to the water. At length the distillation of the hydrocarbons proceeds at a slower rate, the very fine coal which at first obstructed the air-supply is partially burned away, sufficient hot air comes through the bed of hot coke to burn thoroughly all the gases, and such a balance of conditions between the amount of gas generated and the amount of air supplied exists that the best possible conditions for maximum economy are obtained and the chimney-gases are then smokeless. Finally the gases are all distilled, and a bed of coke remains, which, as long as it is thick enough with relation to the air-supply, will burn under good conditions for economy, but as soon as it burns down low and the air-spaces become large enough to allow an excessive supply of air into the furnace, a new condition of poor economy is reached, the excess of air passing up the chimney carrying away heat which should have been utilized in the boiler.

The waste of fuel is not the only loss occasioned by the prevalent wrongful method of burning soft coal. In all western cities the depreciation in value of residence property in the vicinity of factories, the cost of painting and repainting of houses and stores, the constant scrubbing and washing to remove soot, and the destruction of textile fabrics, if they could all be expressed in dollars and cents, would amount to an enormous total.

Smoky Chimneys not Necessary.—All of the loss due to smoky chimneys it is quite possible to avoid, by the use of well-known and well-tried appliances. The principles which govern the complete and

smokeless combustion of bituminous coal are simple enough, but the application of these principles in practice has hitherto been usually considered to involve extra cost of installation of a boiler plant, extra cost of repairs, and extra trouble. The fear of extra cost and trouble, together with exceeding conservatism of factory owners in regard to everything connected with steam-boilers, have been the chief obstructions to the universal use of smokeless furnaces in our western States. These obstructions are, however, rapidly being removed. Many large concerns have recently introduced smokeless furnaces, not to abate a nuisance, but to save fuel and labor, and within a very few years it may be expected that their use will be almost universal in large boiler plants.

How to Avoid Smoke.—Coal can be burned without smoke, provided:

I. The gases are distilled from the coal at a uniform rate.

II. That the gases when distilled are brought into intimate contact with *very hot* air.

III. That they are burned in a hot fire-brick chamber.

IV. That while burning they are not allowed to come in contact with comparatively cool surfaces, such as the shell or tubes of a steam-boiler; this means that the gases shall have sufficient space and time in which to burn before they are allowed to come in contact with the boiler surfaces.

Mr. A. Bement, *Jour. Western Soc'y Engrs.,* 1906, expands III. and IV. so as to read:

"(*b*) That the gases which are distilled uniformly from the coal shall enter a fire-brick chamber of either sufficient length to allow the flames to become entirely consumed naturally or that the chamber be provided with such auxiliary mixing and baffling devices as will cause the gases to be artificially mixed together before the exit of the chamber is reached."

Practical Success of Smoke-prevention.—Mr. Alfred E. Fletcher, Chief Inspector of the Local Government Board in Scotland, in his report for 1892, says:

"Consumers of coal in almost all kinds of furnaces have it now in their power to conform with the requirements of the Public Health Act, and prevent the discharge of black smoke from their chimneys. As a proof of this, one prominent instance can be mentioned of a large chemical works, where may be seen a row of 50 large Lancashire boilers, each with two furnaces, and an equal number of furnaces

applied to other purposes than that of raising steam, making in all as many as 200 fires. Till lately a row of four chimneys poured out a mass of black smoke, which shrouded the whole district in its pall; now they are smokeless as far as color is concerned, and only fully burnt colorless gases are sent into the air."

Progress in Smoke Abatement.*—The most direct evidence of the improvement made in smoke abatement in recent years is in the record of observations of atmospheric conditions taken in many of the large cities. The "black fogs" once so prevalent in London and which have been proven to have been due largely to smoke, are to-day practically unknown. The winter sunshine of London is to-day about 40 per cent of that observed in the country districts, which is a figure double that of 30 years ago. In nearly all of the larger cities a marked improvement along similar lines has been made each year. In the manufacturing districts the boiler users are taking increasing interest in this matter, realizing that it has an important influence upon the efficiency of their plants. The public is also aroused to the situation and the urgency and practicability of smoke abatement seem to be generally appreciated.

Recognition was made of the splendid work done on smoke abatement in Cleveland, Ohio, and Chicago, Ill., where the progress made within the past five years has been remarkable.

During the past year the soot fall of London has been carefully measured by means of specially devised soot gages. The total yearly deposit from the atmosphere was 650 tons per square mile, or a total of 76,050 tons per annum for the entire administrative county of London of 117 square miles. This figure includes 8000 tons of sulphates, 6000 tons of ammonia, and 3000 tons of chlorides, the balance being carbon and tarry products. The deposit per square mile at Surrey, on the border of the metropolitan area, was only 195 tons per year, or less than one-third that of London proper, showing clearly the comparative purity of country air.

Smoke abatement may be best effected in the present state of the art of fuel burning by thorough consideration of the following conditions:

1. Selection of a suitable fuel with provision for maintaining it at a fixed standard of heat value.
2. Scientific study of the conditions prevailing in the plant, including draft, composition of gases, temperatures, etc.
3. Design or selection of type of furnace or apparatus best adapted to meet these conditions.
4. Proper construction or installation of the same.
5. Careful selection of operating force.
6. Suitable instrumental aids or guides for the firemen and responsible engineer.

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* Extracts from a report by George H. Perkins on the International Smoke Abatement Exhibition, held in London, March, 1912. *Jour. A. S. M. E.*, 1912.

7. Frequent and thorough inspection to insure maintenance of the highest possible efficiency.

Methods of Securing Complete Combustion.—The fundamental condition of perfect combustion of soft coal is that every particle of the gas distilled from the coal, including the water-gas made by decomposing its moisture, be brought in contact with a sufficient supply of very hot air to burn it, the mixing of the gas and air taking place at a sufficient distance from the heating surfaces of the boiler so that they do not become cooled below the temperature of ignition before the combustion takes place. It is impossible to secure this condition in an ordinary furnace with hand-firing and a level bed of coal.

It may be secured, however, to a considerable extent with hand-firing if some modifications of the furnace and of the method of firing are made. The change required in the furnace is the roofing of it with fire-brick and the provision of a large fire-brick combustion-chamber in which there shall be sufficient space and time allowed for the separate currents of gas and of heated air to become intimately mixed before coming in contact with the boiler surfaces.

The Coking System of Firing.—The change required in the method of firing is such a change that the whole bed of the fire shall not at the same time be covered with fresh coal. To effect this, either the coking system or the alternate-firing system may be used. In the first, or coking system, the fresh coal is piled up on the front half of the bed while the rear half has a level bed of half-burned coal upon it. The gases distilled from the fresh coal then pass over the rear half, through which an excess of air is entering, being heated as they pass through the bed of coke. The two currents of gas, one containing the distilled gases and the other the supply of hot air, intermingle in the hot combustion-chamber. When nearly all of the gas has been distilled from the pile of coal in the front half of the furnace, the pile is pushed back and levelled over the rear half, and either immediately or within a minute or two, according to whether the gases have been more or less completely driven off, fresh coal is again piled in front. With some coals the coking system cannot be advantageously used, namely, those coals which contain a large quantity of very fusible ash. In pushing back the coked coal onto the rear of the grates, the ash lying thereon, and which may have been kept below the fusing temperature by the air passing through it, becomes mixed with the coked coal, which just after being pushed back burns with great rapidity, generating a very

high temperature, melting the ash and causing it to run and choke the air-spaces in the grate.

The coking system involves a greater amount of labor and attention on the part of the fireman than ordinary level firing, and they sometimes object to it on that account. To what extent he coking system of firing will reduce the amount of smoke depends on the character of the coal, on the skill of the fireman, and on the size of the fire-brick combustion-chamber. The lower the percentage of moisture and volatile matter the less smoke will be made with any system of firing, and the more complete will be its suppression with the coking system. The smaller the quantity of fresh coal fired at a time, and the greater the care exercised by the fireman to keep the quantities fired each time and the intervals between firing uniform, and to keep the bed of coal in the rear level and not too thick, the less will be the amount of smoke. The larger the combustion-chamber in which the currents of smoky gas and of hot gas surcharged with air unite, the longer time will be afforded for their admixture, the more complete will be the combustion, and the less will be the smoke.

Alternate Firing.—A method of firing which seems to have all the advantages of the coking system, and none of its disadvantages, is that known as alternate firing. It consists in firing fresh coal, first on one half of the bed of the furnace, and then on the other half, alternately, at equal intervals of time. Instead of covering the whole bed with fresh coal, say every ten minutes, only half the bed is covered at each firing, and the other half is covered five minutes afterwards. After each addition of fresh coal the volatile gases that arise from it come in contact with the current of hot gas, carrying an excess of air, which arises from the half-burned coal on the other half of the bed. In this system of firing the fresh coal may be fired alternately, either in the front and rear of the bed, or on the right and left side, the former being called alternate front and back firing, and the latter alternate side firing. With this system of firing the successful prevention of smoke depends largely on the skill of the fireman, but more especially on the size of the combustion-chamber, and the opportunity it affords for thorough admixture of the two currents of gas. Baffle-walls placed in the combustion-chambers to compel the gases to take a circuitous direction facilitate the mixture, and together with the side walls and fire-brick roof, have what is called a regenerative action, on the principle of the Siemens regenerators, used in steel-melting furnaces, absorbing heat during the times when the burning gases are the hot-

test, and giving out heat to the gases when they are cooler, or immediately after the firing of fresh coal.

Alternate firing is of no use unless there is a large combustion-chamber in which the two gaseous currents are mixed and the smoke burned before they are allowed to come in contact with the heating surface.

The "Wing-wall" Furnace.—This furnace was patented by the author May 17, 1898. It is adapted for the smokeless combustion of

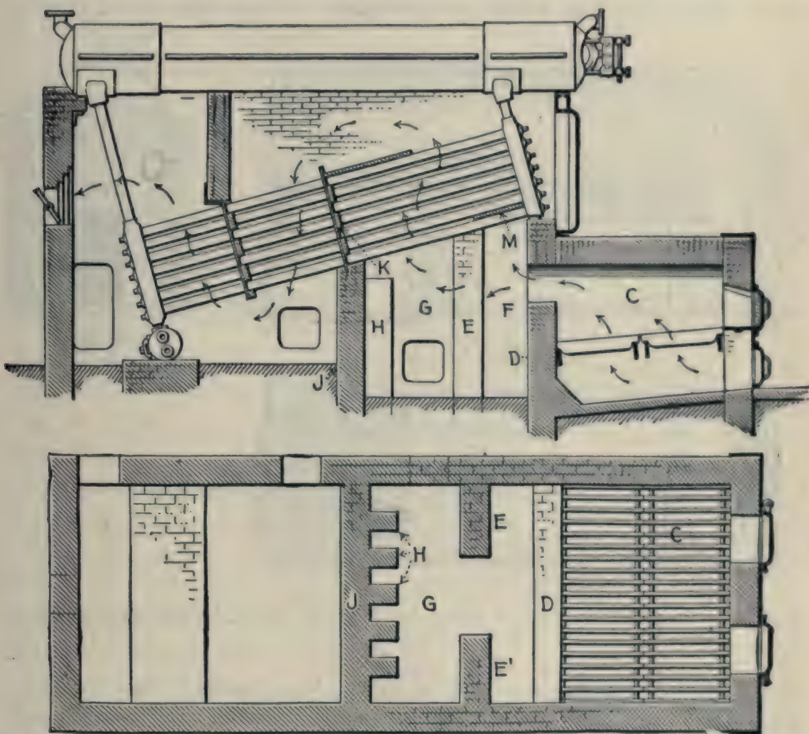


FIG. 17.—THE "WING-WALL" FURNACE APPLIED TO A WATER-TUBE BOILER.

soft coal, peat, wood, tan-bark, and other fuels that contain large proportions of volatile matter and moisture.

The drawings, Fig. 17, show the furnace applied to a water-tube boiler. *C* is a fire-chamber or oven, built of brick and extending out in front of the boiler. In it the fuel is burned, either on the ordinary grate-bars or by means of a mechanical stoker. *D* is an ordinary bridge wall. *EE′* are two tall vertical walls called wing-walls, built

some distance in the rear of the bridge wall. G is a combustion-chamber. HH are several piers of fire-brick, projecting into the chamber G, from the rear wall J. K is the ordinary partition wall built across the boiler-tubes, and M is a tile roof to the chamber F to prevent the gases in that chamber from reaching the tubes until after they have passed through the narrow vertical passage between the wing-walls EE'.

In operation with hand-firing, the alternate method of firing is used. The fresh coal is spread alternately on the right and left sides

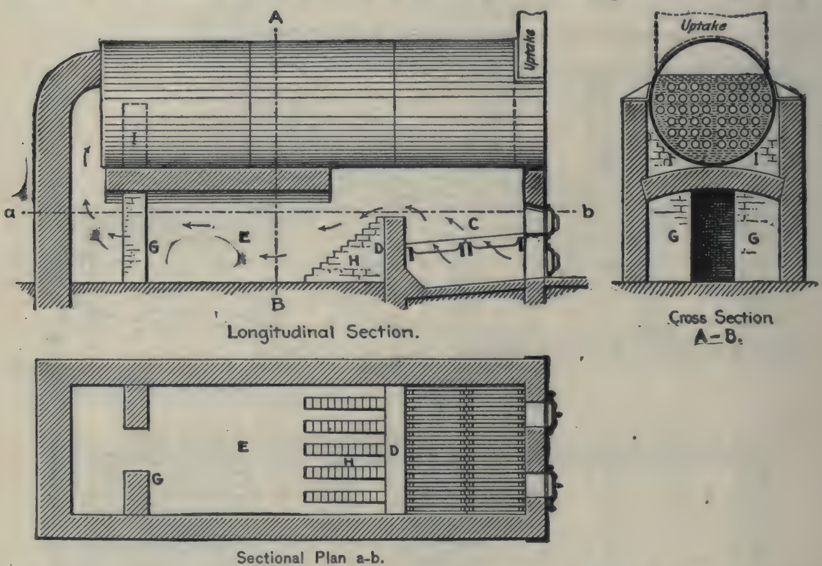


FIG. 18.—THE "WING-WALL" FURNACE APPLIED TO A HORIZONTAL TUBULAR BOILER.

of the grate at equal intervals of time. Immediately after firing on one side dense, smoky gases arise on that side, while on the other side an excessive supply of very hot air is passing through the bed of partially burned coal or coke. These two currents, one of cool, smoky gas and the other of clear, hot gas with a large excess of air, pass side by side over the bridge wall D, but they are compelled to change their direction and mingle together on passing through the tall narrow passage between the wing-walls EE', and by so mingling, the gases are burned and smoke is prevented.

The combustion is assisted by the heat radiated from the walls of the combustion-chamber G and the piers H, which absorb heat dur-

ing the time when the fire is hottest—that is, just before fresh coal is spread on the grate, and give out heat to the gases in the chamber *G* when the fire is coolest—that is, just after firing, when the smoky gases are escaping.

Fig. 18 shows a modification of the furnace applied to a horizontal tubular boiler (patented April 23, 1901). In this arrangement the oven built in front of the boiler is dispensed with, and the space in the rear of the bridge wall is used for a combustion-chamber. *GG* here are the wing-walls, and *II* an intercepting wall, built so as to prevent the gases passing over the arch.

Introduction of Heated Air into the Furnace.—The admission of heated air into the furnace, through hollow bridge and side walls or through channels in fire-brick arches over the furnace, has long been a favorite method of inventors of appliances for producing smokeless combustion, and numerous patents have been taken out for such appliances during the last fifty years or more. The theory of this method of improving combustion is correct, but it has usually failed to come into extensive use on account of practical difficulties. The usual troubles are that the air is not made hot enough, that not enough air is introduced into the furnace at the time when it is needed, that is, just after fresh coal has been fired, and too much is admitted when little or none is needed, or when sufficient air is passing through the grates. The air-passages also are apt to become clogged with dust. Sometimes air is forced into the passages by means of a steam-jet, and some benefit in diminishing smoke is apparent, but a loss of economy usually results, and the use of the jet is abandoned. Automatic appliances for admitting air just after firing, and shutting it off gradually during two or three minutes following, have also been used sometimes with apparently good results, but they do not appear to have been generally successful. Admitting cold air above the coal will be of no use to burn these gases unless it becomes highly heated after its admission by contact with or radiation from the hot walls of the furnace and combustion-chamber. When there is a long fire-brick combustion-chamber in the rear of the furnace in which the air and gases may unite, the automatic admission of air just after firing, and its gradual shutting off may prove beneficial both in diminishing smoke and in improving economy.

Jets of steam are sometimes blown into the furnace, above the fire, carrying jets of air with them, on the principle of the injector. That they do decrease the amount of smoke in some cases there seems to

be no doubt. Reasons which have been given to explain the action of the jet and which may to some extent be true are the following:

(1) The diminution of smoke is apparent and not real. Both the air and the steam dilute the smoke, and make it less dense in appearance as it escapes from the top of the chimney. The steam also escaping from the chimney as a white cloud disguises the smoke and may condense its bulk, rendering it less visible. Further, the chilling action of the air and steam may decrease the rapidity of production of the smoke in the furnace, extending its production over a longer period of time, decreasing its density during that time.

(2) The jet of air violently driven in by the steam and pointed downwards onto the bed of coal, becomes intimately mixed with the gases distilled from the coal, and then if there is a long run through the hot combustion-chamber the mixture will be burned, destroying the smoke.

The steam-jet is in itself a wasteful appliance, for even if the steam is decomposed and the gases aterwards completely burned, forming steam again, it escapes from the boiler superheated to the temperature of the flue gases, which temperature is always higher than that of the steam in the jet, and there is a consequent loss of heat due to the superheating.

Tests of Steam-jet Smoke Preventers. (J. A. Switzer, *Power,* Jan. 16, 1912).—The boiler plant of the Knoxville Ry. & Light Co., consists of three 300 H.P. Stirling and five 600 H.P. Babcock & Wilcox boilers. Using Jellico, Tenn., coal, hand fired, the smoke was excessive and the efficiency of boiler and grate was only about 60%. After the installation of a steam-jet and door-closing device it was estimated, from observations with the Ringelmann smoke chart that 90% of the smoke had been abated, and a boiler test on the Babcock boilers gave an efficiency of 77% when they were driven at 85% of their rating.

The very low efficiency of the boiler without the apparatus is explained by the fact that the boiler tubes were heavily coated with soot. Fig. 19 shows the relative appearance of the stacks before and after the use of the apparatus.

The smoke-consuming apparatus consists of a steam line terminating in jets placed just inside the special fire doors which are fitted with dashpots connected by a lever system to automatically controlled valves. The arrangement is such that when a door is opened for stoking the steam is automatically turned on and discharged into the combustion-chamber. When the door is closed after firing, the steam continues to blow, and dampers on the door are held open for

a period of three or four minutes; then the motion of the dashpot slowly closes the dampers and throttles the steam.

The action in abating smoke is as follows: When fresh coal is fired upon the hot fuel bed, the combustible volatile matter begins instantly to distill in great quantity. For the complete combustion of this gas an increased supply of air is immediately required. The steam jets create the draft and the open dampers furnish the avenue for the admission of this supply of air. But in addition to fulfilling this function, the jets by a swirling action serve to bring about a complete mixing of the air and combustible gas, thus insuring

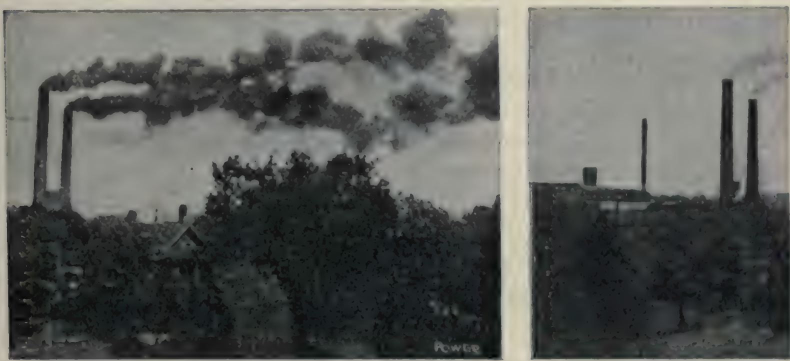


FIG. 19.—APPEARANCE OF STACKS BEFORE AND AFTER USE OF JETS.

practically complete combustion before the burning gases can come into contact with the heating surfaces.

A Superheated Steam Jet.—In the Luckenbach steam jet system, which has been introduced to a considerable extent in Chicago (*Eng.*

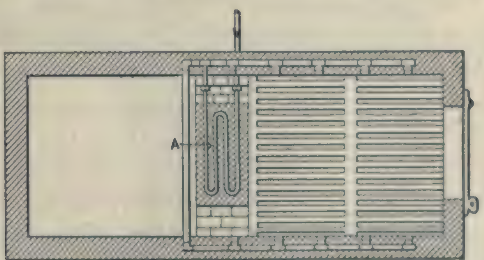


FIG. 20.—FURNACE WITH SUPERHEATED STEAM JET.

News, Dec. 29, 1910), highly superheated steam issues as fine needle jets from orifices located in the furnace walls at a little distance above the fire. The effect of these jets, issuing from opposite sides of the furnace at high velocity, is to thoroughly mix the combusti-

ble gases rising from the coal with the oxygen of the air. Steam taken from the boiler is led to a heavy casting built into the bridge wall, as shown at *A* in Fig. 20. This casting contains a pipe coil through which the steam passes on its way to the jets. A valve in the supply pipe is connected to a mechanism operated by the fire door, so that the valve is opened at the same time with the fire door and is automatically closed at a certain interval after the fire door has been closed. Thus the jets are operated during the time when the fresh coal thrown on the fire is giving off a large volume of gases which would appear as smoke if not consumed. After the fire is bright, and there is no further need for the mixing action, the steam valve is closed.

Downward Draft Furnaces.—In ordinary hand-fired furnaces, fresh coal is fed on top of the bed, and the air passes upwards through the grate, then through the very hot partially burned coal or coke lying on the grate, and finally through the fresh coal from which the volatile gases are being distilled. If the direction of the draft can be reversed, the air being admitted above the coal and passing down through it and through the grate, the character of the operation of the furnace is completely changed. The cold air and the cool distilled gases pass together down through the hot coke, and if the air-supply is sufficient the gases will be thoroughly burned and smoke will be prevented. To prevent the burning out of the grate-bars they are made of water-tubes, which are connected by headers with the boiler so as to insure a positive circulation of the water through them.

The Hawley Down-draft Furnace.—This is a form of down-draft furnace which has for more than twenty years been widely introduced in the United States, and has given excellent results both in smoke-prevention and in economy of fuel. Besides the water-grate upon which the coal is fed, there is a lower or common grate, upon which is burned the coke that falls through the water-grate. The greater part of the air-supply is admitted above the fresh coal on the water-grate, passing through the coal and an additional supply is admitted below the lower grate, passing upwards through it to burn the coke and to assist in burning the gases. The space between the two grates forms part of the combustion-chamber in which the gases are burned.

Fig. 21 shows a Hawley furnace as applied to a Heine water-tube boiler and Fig. 22 a view of the water-grate. The pipe-connections by which a circulation of water is insured through the water-grate are also shown in Fig. 21.

Automatic or Mechanical Stokers.—By the use of mechanical stokers the chief objections to hand-firing are avoided, viz., the intermittent supply of coal, the sudden volatilization of great volumes of

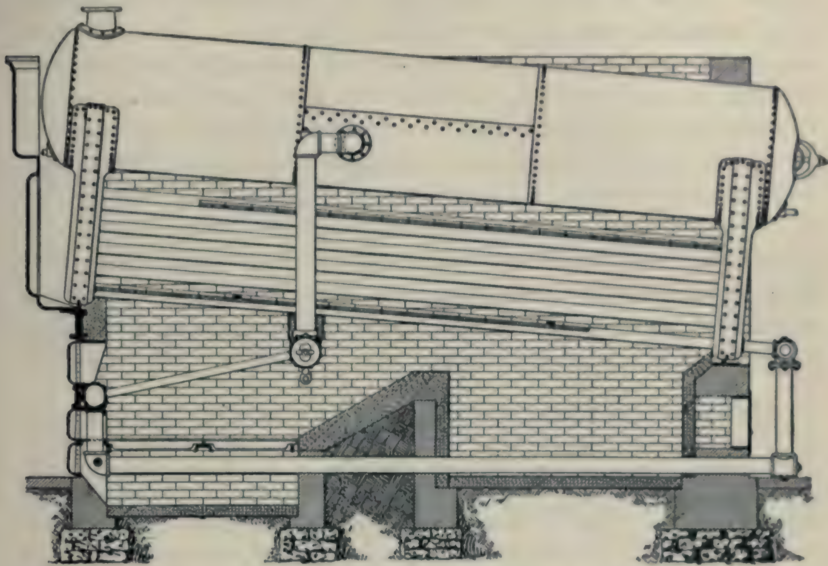


FIG. 21.—HAWLEY DOWN-DRAFT FURNACE APPLIED TO A HEINE BOILER.

smoky gas, the alternately deficient and excessive air-supply, and the cooling due to frequent opening of the fire-door. When properly

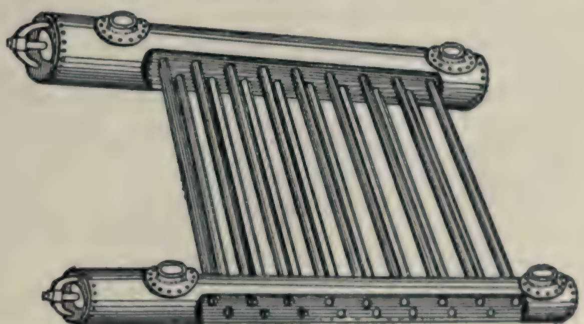


FIG. 22.—WATER-GRATE USED IN THE HAWLEY FURNACE.

designed and operated these stokers feed both the coal and the air at a regular rate, and when the air and the coal-supply are properly adjusted to each other, and proper provisions, such as a fire-brick

combustion-chamber or other means, are made for compelling the currents of gas and air to become completely intermingled, they will burn coal without smoke and at same time with the maximum economy which the design and proportions of the boiler permit. Moreover, in large plants they are capable of effecting a great saving of labor, especially when they are used in conjunction with modern methods of storing coal in overhead bins and feeding it by gravity through chutes into the hoppers of the stoker. The chief objection to them is their initial first cost. In large well-designed plants, however, this objection is to a great extent, if not entirely, overcome by the fact that when the stokers and their rate of driving are properly proportioned to the boilers, it is possible to obtain from a boiler considerable increase of capacity compared with hand-firing, without any sacrifice of economy, and therefore the number of boilers required may be less than with hand-firing.

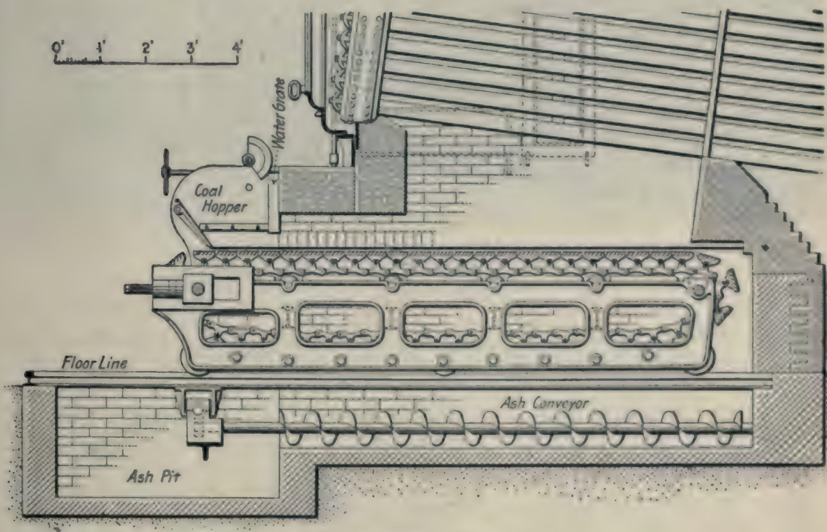
Advisability of Installing Stokers.—The cost of stokers is greatly in excess of the cost of hand-fired furnaces. The upkeep cost of the furnace is greater than in hand-fired practice. From their greater first cost and the more severe nature of the service, the depreciation will be greater than in the case of hand-fired furnace material.

Automatic stokers require a higher degree of intelligence on the part of the operating crew than do hand-fired furnaces, but such an objection is largely overcome by the present-day tendency toward the employment of a better class of labor in the boiler room. An early objection to stokers in general had its basis in the fact that the ash contained an excessive amount of unburned carbon. This objection also has been largely overcome by improvements in design of practically all stokers.

The question of the advisability of a stoker installation is one which must be considered most carefully in all of its phases. The added efficiency and capacity, the labor saving possible, and the smokelessness must be balanced against the added first cost or interest on the investment, the depreciation and maintenance cost, the steam required for stoker drive or blast, and the added cost of furnace upkeep. In general, a stoker installation will be found profitable in the larger plants properly equipped for handling the fuel and ashes. In small plants such an installation may be advisable only where the question of smokeless combustion is paramount. (From Babcock & Wilcox Co.'s book on Chain Grate Stokers.)

Types of Mechanical Stokers.—The stokers now in common use may be divided into four general classes, depending on the kind of mechanism used for feeding the coal. In the first class the coal is

carried on grate-bars, either horizontal or inclined more or less, the individual bars, or sometimes alternate bars, being given a reciprocating to and fro, up and down, or rocking motion, by which the coal is gradually advanced along the grates. In the second class the grate is steeply inclined, and the coal is pushed onto its upper end, and slides down slowly as it burns. In the third class the whole grate forms an endless chain of short bars, on which the coal travels horizontally into the furnace, the chain passing over a sprocket-wheel at the end and returning through the ash-pit. In the fourth class the fresh coal is fed in underneath the burning coal, and the gases distilled from it pass through the bed of hot coke above, the action being exactly the reverse of that of the Hawley down-draft furnace, in which the fresh coal is fed on the top of the bed, and the gases pass down through the bed of hot coke beneath. A brief description of some modern forms of stokers will now be given.



Longitudinal Section.

FIG. 23.—THE PLAYFORD STOKER.

The Chain-grate Stoker.—Fig. 23 shows the Playford stoker. To the travelling-chains are attached a series of wrought-iron T bars, running across the furnace, and these carry the small cast-iron sections of which the grate is made. Below the chain-grate a screw-conveyor

is placed for carrying the ashes forward from the rear of the furnace to the ash-pit in front.

The Babcock & Wilcox Stoker, Fig. 24, is also an endless-chain grate. It has been used with much success in the West with bituminous coals. The cut shows the stoker removed from the furnace. It is driven by a worm-wheel, the power being delivered to the worm from an independent engine through a lever and ratchet-wheel. The

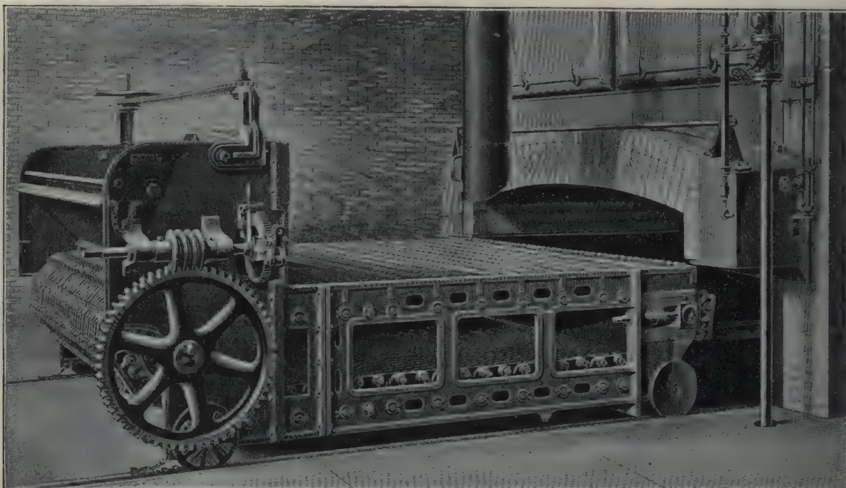


FIG. 24.—THE BABCOCK & WILCOX STOKER.

large vertical pipe is the coal-feeder, which delivers coal from the overhead bin into the hopper.

Notes on Chain Grate Stokers. (Discussion of a Paper read before the Cleveland Engineering Society, *Indust. Eng.,* Nov. 1913).—When chain-grate stokers are used the coal should be crushed so that 85 to 90 per cent will pass through a ¾x¾-in. screen.

Chain grate stokers to properly handle coking coals must have an ignition arch of proper construction so that the coal is coked before it leaves the forward end of the arch. To better accomplish this uniform ignition, instead of using sprung arches, flat arches are now generally installed. These give a better distribution of the gases across the furnace, as the gases do not have the tendency to draw to the center that they have when a sprung arch is used. Where coals coke readily under the ignition arch a crust forms which cuts off the proper air supply, but with non-coking coals there is little trouble

from this crusting over, and the air supply at this point is not so much interfered with.

To provide a sufficient air supply under the ignition arch when a coking coal is used, air has been introduced through a row of small openings in the arch above the coal just as it leaves the hopper, resulting in diminished smoke and increased economy.

Joseph Harrington described a "reflecting arch," a long or inclined arch so placed that the heat from the rear or incandescent portion of the fuel bed is directly reflected to the incoming fuel at the gate. Its height and inclination render it possible to utilize for ignition purposes the direct radiation from the face of the bridge wall. It is of the utmost value even though it may be anywhere from nine to twelve feet away from the gate. By means of this type of arch setting, great intensity of ignition effect prevails and a rapidity of combustion may be secured thereby which is difficult or impossible with certain other types of settings. Satisfactory ignition with grate speeds up to 10 or 12 inches a minute can readily be attained, which corresponds to a rate of combustion exceeding 50 pounds per square foot. These high rates can only be attained with fuel bed thicknesses which will permit of the application of high draft. All of the conditions which produce high efficiency may be present in a plant, but if left to the eye they will not be effectively used. Instruments of precision are absolutely required, such as a recording draft gage in the furnace and at the damper, a CO_2 chart, and a recording thermometer in the uptake. It is only by the careful watching of such instruments that the entire plant can be operated at anywhere near the maximum efficiency. D. S. Jacobus stated that in European chain-grate practice, air is often admitted at the front of the stoker. In some cases the air is pre-heated. Air admitted in this way reduces the smoke and careful gas analyses and station records have shown that if the proper amount of air is used, there is no falling off in the economy. The chart illustrating the falling off in economy with different percentages of CO_2 shows that the proportionate gain in maintaining CO_2 higher than 12 per cent is not as great as by increasing the percentage from a lower amount of CO_2 to this figure. If an increase in the amount of CO_2 above 12 per cent is accompanied by the formation of carbon monoxide, the gain will be less than shown by the chart. With no CO present, 12 per cent of CO_2 is just as favorable an analysis for economy as 14% CO_2 with 0.3% of CO. Often in making gas analyses a small amount of CO will not be detected. In obtaining the highest efficiencies it is of great importance to accurately measure the CO, which can be done more surely by using a Hempel apparatus, where the gas is shaken up with the solution, than by using an Orsat apparatus.

Tile Roof Setting with Transverse Gas Passages.—Fig. 25 shows a setting designed by A. Bement for the Cedar Rapids (Iowa) City Railway and Light Co., and described by him in the Journal of the

Western Society of Engineers, 1908. It was designed for highly volatile Western coals and has given excellent results. Mr. W. J. Greene of the Cedar Rapids Co. says of it after 15 months service:

When this boiler was installed for us, in addition to the fear that the circulation of the water would be reversed, many persons sug-

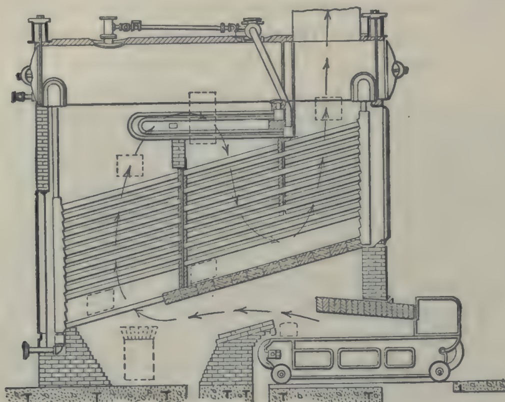


FIG. 25.—TILE ROOF AND TRANSVERSE PASSAGES.

gested other difficulties that would be encountered, namely: that explosive gases would collect in the first passage just under the drums and when mixed with air coming through the fire would explode, causing damage to brick-work; that dust would collect in the open spaces between the first and second rows of tubes so rapidly as to

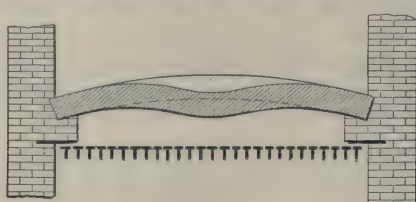


FIG. 26.—FAILURE OF IGNITION ARCH.

seriously cut down the draft or cause much extra work to keep the dust removed; and that the baffle walls could not be kept in place. None of these troubles have been encountered. As to the dust, with the exception of a small accumulation at the front water legs and first baffle, the passage is kept clear by the draft and requires no cleaning. The baffle walls have given no trouble whatever.

In the discussion of Mr. Bement's paper the author criticised a minor feature of the setting, the extension of the arch over the

fire into a region where it was surrounded entirely by intensely hot gases, and Mr. Bement replied as follows:

Professor Kent's criticism of the extension of the ignition arch so far into the furnace is excellent, and his prediction that it would burn out shows excellent judgment, because this is just what did happen to it. After it had been in use for something like two months, it failed by settling down in the center as shown by Fig. 26. There is really no occasion for such a long arch, because a corresponding effect may be obtained from the presence of the tile furnace roof.

The Roney Mechanical Stoker.—This stoker was first brought out in 1885. The present construction is shown in Fig. 27. It receives

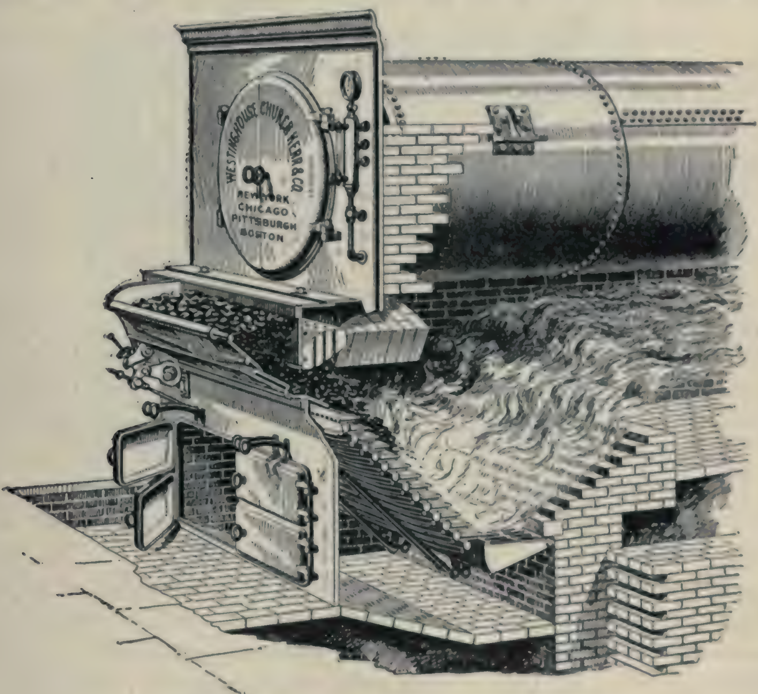


FIG. 27.—THE RONEY MECHANICAL STOKER.

the fuel in bulk, and, without further handling, feeds it continuously and at any desired rate to the furnace, burns the combustible portion and deposits the ash and clinker in the ash-pit ready for removal.

In the bottom of the coal-hopper is located a sliding pusher, which gradually feeds the coal over the dead-plate and on to the grate. The latter consists of horizontal flat surfaced overlapping bars, extending

from side to side of the furnace, and inclined at an angle of 37 degrees from the horizontal. In the wider furnaces two or more sets of grate-bars are placed side by side, provided with independent actuating connections. The grate-bars rock in unison, assuming alternately a stepped and an inclined position. When they rock forward into the inclined position the burning coal tends to work down in a body, but before it can move too far the bars rock back to the stepped position, checking the downward motion, breaking up the bed of fuel and freely admitting air through the fire. This alternate starting and checking motion keeps the fire constantly stirred and opened up from beneath, and finally lands the cinder and ash on the dumping-grate, from which it is discharged into the ash-pit. The depending webs of the grate-bars are perforated with longitudinal slots, so placed that the condition of the fire can be seen at all times and free access had to all parts of the grate without the opening of doors. These slots also serve to furnish an abundant supply of air for combustion. The motion of the grate-bars and the feeding device is regulated by two simple adjustments, by which the action of the stoker is controlled and the fires are forced, checked or banked at will.

A coking-arch of fire-brick is sprung across the furnace, covering the upper part of the grate and forming a gas-producer whose action is to coke the fresh fuel and release its gases, which, mingling with heated air, supplied in small streams through the perforated tile above the dead-plate, are burned in the large combustion-chamber above the bed of incandescent coke on the lower part of the grate.

This stoker burns all kinds of coal, from lignite to anthracite, and also waste products, such as tanbark, sawdust, cottonseed hulls, and coke "breeze," without change of grate-bars.

The Murphy Automatic Furnace is shown in cross-section as applied to a horizontal tubular boiler in Fig. 28. The furnace is also applicable to all forms of fire-tube and water-tube boilers. The grates are of a "V" form and in pairs, the upper ends resting on the magazine bed-plate, which is also the feed- or coking-plate, while the lower ends rest in niches on the grate-bearer, which also contains the clinker-bar or clinker-breaker. A fire-brick arch is sprung across the furnace, covering the grate-surface, and on top of each side of the arch there is an air-flue from which hot air is supplied through the series of small openings at the bases of the arch where the brick rests on the ribbed surface of the arch-plates on either side of the furnace. This gives a double side feed- and coking-plate. The coal magazines

are provided with stoker-boxes, which are connected by means of pinion-gears to the stoker-shaft, which is automatically moved back and forth, stoking the coal into the furnace. One grate of each pair of grates is fixed, while the other is movable up and down by a rocker motion at the lower or center end, thus keeping the fire free from ashes while the coarse refuse and clinker is worked down to the center, where a rotating clinker-bar grinds it into the ash-pit. The entire operating mechanism is attached to a flat iron bar running across the outside of the front, and operated by a little automatic upright engine set at the corner of the setting, which uses about one horse-power per

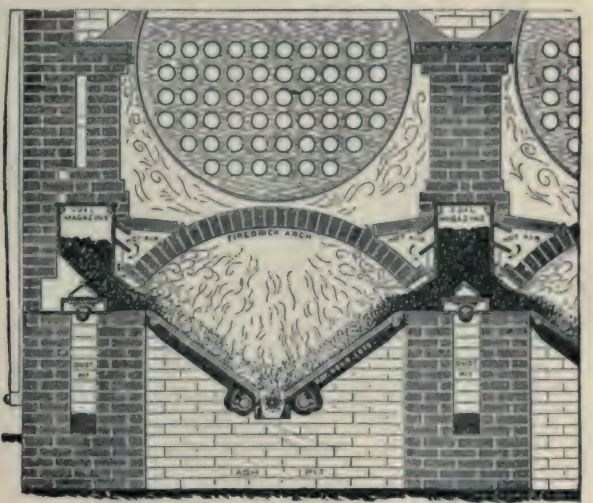


FIG. 28.—THE MURPHY AUTOMATIC FURNACE.

furnace operated. Each revolution of the driving-gear stokes a given but variable quantity of coal into the furnace on each side, moves half of the grate-bars on each side up and down, and turns the clinker-bar partly around. Thus the coal is fed and the fires cleaned constantly. The teeth on the clinker-bar are prevented from becoming hot and worn off by means of a current of air passing through the open center of the bar and piped to the flue or stack beyond the damper.

The clinker is kept brittle and prevented from sticking by a spray of exhaust steam distributed through a pipe cast into either side of the grate-bearer.

The Jones Under-feed Stoker (Figs. 29 and 30) was patented in 1896 by E. W. Jones of Portland, Oregon. The fresh coal is pushed

up through the bed of burning fuel by means of a steam-ram, operated by a hand-lever connected to a valve, by means of which the charges of fuel can be delivered as required. Air at about four ounces pressure is forced through the tuyere-blocks, and up through the heap of burning fuel, and, mingling with gases from the coking coal, produces an intense and rapid combustion. Owing to the large

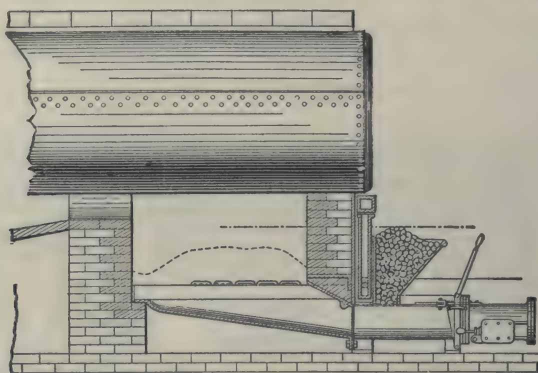


FIG. 29.—THE JONES UNDER-FEED STOKER.

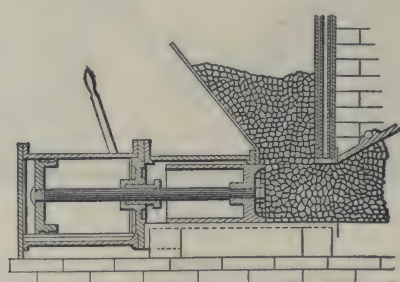


FIG. 30.—CYLINDER OF THE JONES STOKER.

excess of air delivered at high pressure, and its thorough mingling with the gases, a practically smokeless combustion is obtained. This stoker has been principally used with low-grade Western American bituminous slack coal.

The "Taylor" Gravity Underfeed Stoker.—Fig. 31 is a development of the underfeeding principle of the Jones Stoker. It differs from that stoker in that the retorts or fuel magazines are inclined, permitting the ashes formed on the surface of the fuel bed to be dis-

posed of at the rear or bridge-wall end of the furnace, instead of at the sides of the retorts. The coal descending from the hopper is pushed forward by an upper plunger into the fuel magazine, a space between two adjoining tuyere or inclined air boxes. A lower plunger working in the bottom of the fuel magazine with an adjustable stroke pushes the green and partially coked fuel toward the bridge-wall and assists the ash down the inclined fuel surface. The partially consumed coke and ashes gradually descend onto an extension overfeed grate and thence on to a dump plate at the rear of the stoker, as illustrated, or in

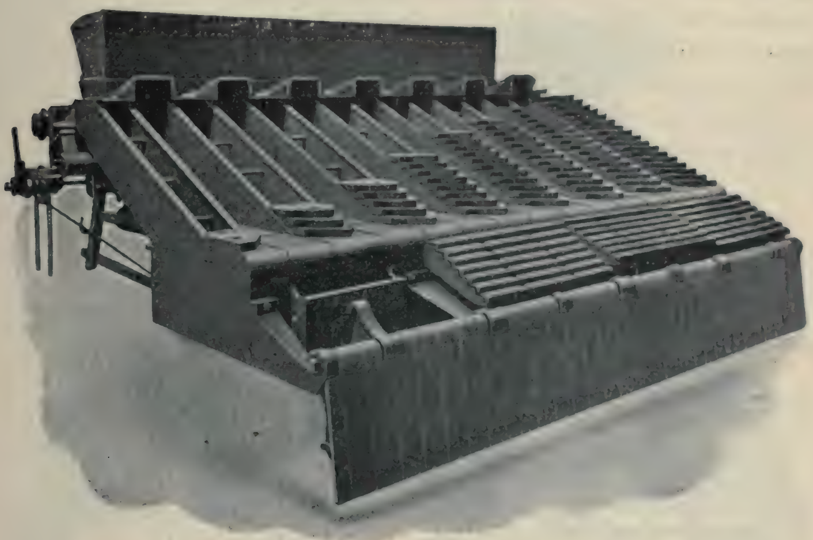


FIG. 31.—THE TAYLOR GRAVITY UNDERFEED STOKER.

some cases onto an automatic ash discharge and crusher. Here the mixed coal and ashes are allowed to remain for a sufficient length of time to consume the larger portion of the combustible. The speed of the rams and the rate of fuel are so arranged as to maintain a depth of from 18 to 30 inches of fuel bed above the tuyeres.

The tuyeres consist of cast-iron plates with horizontal passages which deliver the air horizontally into the coal as it travels out of the mouth of the fuel retorts. The cut shows some of the plates removed.

Fig. 31 shows a view from the bridge-wall of a large stoker consisting of seven fuel magazines or retorts, each equipped with an upper

and lower plunger. The upper and lower plungers are driven through connecting rods from a slowly revolving crank-shaft. The crank-shaft is in turn driven through two trains of worm gearing. Each gear box or set of gears drives a maximum of four retorts. The speed shafts of the gear box are connected through chains and shafting to the shaft of a volume blower.

The blower is arranged to run at a variable speed, its operation being automatically controlled by the demands for steam. Any change in the speed of the blower results in a change in the flow of air delivered and in a change in the rate of fuel feeding, so that a constant ratio of fuel fed to air supplied is maintained. The fixing of the ratio between the air and coal is determined by analyzing continuous samples of flue gas.

Results of tests on boilers equipped with Taylor stokers will be found in a later chapter.

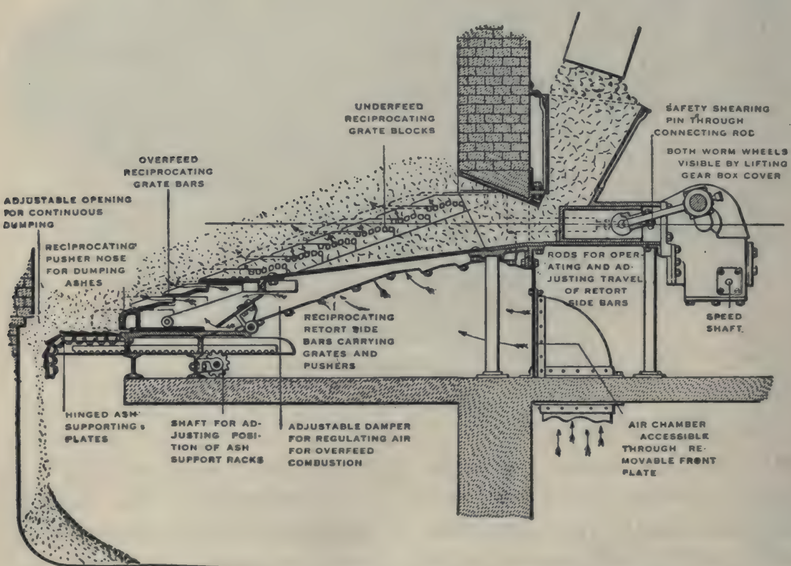


FIG. 32.—THE RILEY SELF-DUMPING UNDERFEED STOKER.

The Riley Self-dumping Underfeed Stoker is of the inclined underfeed type, that is, the coal is forced up from beneath the point where the air is admitted, and then is worked along toward the bridge wall. Instead of stationary dead plates, it has moving air-

supplying grates, carried by the reciprocating sides of the retorts, and also moving overfeed grates, extending across the entire width of the stoker. Beyond these are pushers for continuously dumping the refuse. The travel of these reciprocating parts is adjustable so as to control the movement of the fuel bed and dumping of refuse. Fig. 32 is a longitudinal cross-section, and Fig. 33 a view from the bridge-wall of a five-retort stoker.

The incline of the retorts and grates is so slight that the fuel bed does not move except as it is mechanically propelled. Recipro-

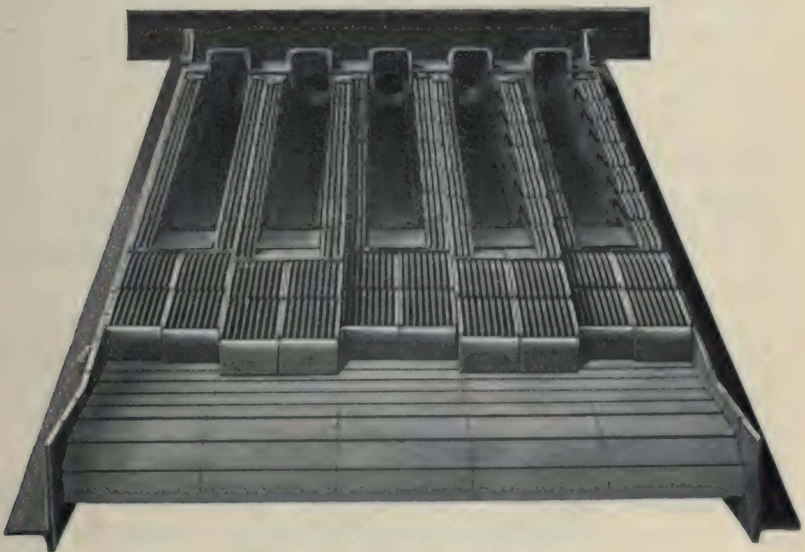


FIG. 33.—THE RILEY STOKER.

cation of alternate retort sides in opposite directions keeps the coal in motion slowly along the incline, distributing it evenly.

This reciprocating action is the distinctive feature of this stoker and causes an action in the fuel bed somewhat different from that in any other type of underfeed stoker. There is a more or less well defined slicing action along the lines between adjacent retort sides. This serves to keep clinkers broken up and furnishes a ready exit for hot gases which might otherwise have a destructive reverberatory action under large clinkers.

The upper edges of the reciprocating retort sides carry grate

blocks, which are really narrow grates with side tuyere openings for allowing air to enter the green fuel below the zone of combustion. These grate blocks are baffled so that while they allow air to escape freely, they do not allow fuel or ashes to sift through into the air chamber below. Beyond the end of the underfeed retorts the overfeed grates of the same type extend the entire width of the retorts. The air for the overfeed grates is less in pressure than the underfeed air, and is at all times under the control of the operator.

The reciprocating motion of the retort sides and of the overfeed grates produce a continuous movement along the slope to the pusher noses which push the refuse slowly back toward the bridge wall until it drops through the opening. The dumping capacity of the stoker is equal to the displacement of the pusher noses, and this is regulated by the amount of travel given to the retort sides, which is adjusted in proportion to the percentage of ash in the fuel. The dump is continuous and automatic, after allowing the refuse time enough to become thoroughly burned out and practically cold. The ash pit is in a separate compartment which need have no communication with the fire-room.

The stoker and its forced draft fan are coupled together so that the ratio of air to fuel remains constant, no matter how the load fluctuates. The proper ratio of fan and stoker speed is fixed from flue gas analysis. This regulator ratio is never changed unless there is a radical change in the kind of fuel.

Mechanical Stokers for Locomotives.—Several forms of stoker have been tried on American locomotives, and two of them, the Crawford underfeed and the Street overfeed, appear to have given fairly satisfactory results as to developing the fullest capacity of the locomotive boiler. Thirty of the Street stokers were in operation and 69 under construction, as a result of the good performance of the 30, in 1912. (See report of a committee of the Am. Ry. Mast. Mechs. Assn., 1912, *Eng. News,* June 27, 1912.)

Burning Illinois Coals without Smoke.—Prof. L. P. Breckenridge describes in Bulletin 15 of the University of Illinois Engineering Experiment Station a series of tests of four types of water-tube boilers with different kinds of stokers, to determine the rate at which the boiler could be driven without making smoke. The following table shows the principal results:

No.	Type of Boiler.	Stoker.	Baffling.	Rated Capacity. H.P.	Per cent Rated Capacity without Smoke.
1	B. & W.	Chain grate	Vertical	150	50 to 120
2	Stirling	" "	Usual	260	50 to 140
3	National	" "	Vertical	250	50 to 120
4	B. & W.	Roney	"	220	up to 100
5	"	"	Horizontal	220	50 to 100
6	Stirling	Stirling	Usual	260	50 to 140
7	Heine	Chain grate	Horizontal	210	50 to 140

NOTES.—In No. 4 there is only a short arch over the stoker, and the bottom row of tubes is not protected by fire-brick. This unit when handled carefully can be run up to capacity without smoke above No. 2 on the Ringlemann chart. It requires careful attention and at capacities above 100% cannot be run without objectionable smoke except by expert firemen. No. 5 is the same as No. 4 except that there is a tile roof furnace and baffling parallel to the tubes. It can be run from 50 to 100% of capacity without smoke.

No. 2 has the chain-grate covered for nearly its whole length with fire-brick arches, and has a very large combustion-chamber. It operates easily without smoke at capacities from 50 to 140%.

No. 7 can be run easily at from 50 to 140%. It is almost impossible to make smoke with this setting under any condition of operation. The setting is shown in Fig. 34.

The tests above described were all with water-tube boilers. In the same Bulletin Prof. Breckenridge discusses the problem of burning Illinois coals without smoke under fire-tube boilers as follows:

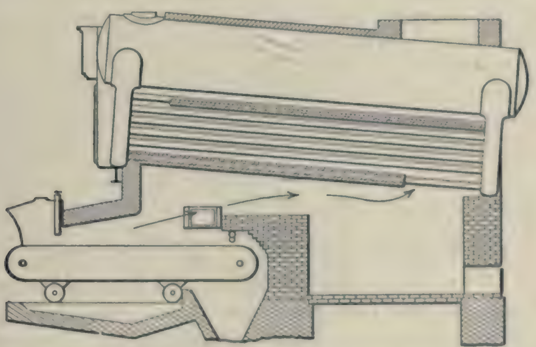


FIG. 34.—A SMOKELESS FURNACE.

The horizontal fire-tube boiler is still much in use in smaller units of 50 to 150 H.P. With Illinois coals carrying 30 to 40 per cent of volatile combustible matter and burned at rates which produce flame lengths of from 5 to 20 feet, there is no better method of producing dense black smoke than to install a horizontal fire-tube

boiler with the usual furnace, and hand-fire such a plant with a run-of-mine coal. The method of introducing the coal directly into the hot furnace, in fine dust and large lumps, prevents slow or uniform distillation of the gases; the air supply through open doors, through holes in the fire, or through a fuel bed of varying thicknesses is neither correct in quantity nor is much of it properly heated; the mingling products of combustion come in contact with the cool surface of the plates of the boiler, reducing the temperature of the gases below the ignition temperature before combustion is completed.

It is possible to burn Illinois coal without smoke with fire-tube boilers, but the furnace requires special treatment. The plans usually proposed are either low-set stokers or extended Dutch oven furnaces. When hand-firing is adopted the wing-wall furnace or other form of mixing baffles or piers is of great assistance. With any of these devices careful firing is very necessary for satisfactory results. The best method of hand-firing for smokelessness is also the best for attaining economy. There are three generally recognized methods of hand-firing: (*a*) The Spreading, (*b*) The Coking, and (*c*) The Alternate. The first is satisfactory for anthracite; the second for coking coals and the last for non-coking coals. It is the alternate method that is best suited to Illinois coals. This method is described as follows: The fuel bed area is divided into equal parts, two, four, or six, depending on the size of the entire surface. The fresh coal is fired alternately on one-half of these areas at a time at such intervals as may be necessary to hold the steam pressure. Depending on the rate of driving, these intervals will vary from one to five minutes. When the fuel bed area is very large, some checker-board system of firing may be adopted which, when alternately fired and left free for air passage, will result in a large reduction in the amount of smoke produced by the too common method of spreading the coal over the entire surface at each firing. It may be advantageous to provide for still more air by leaving the fire doors open slightly just after each firing. There are several devices on the market which provide for an air supply over the fire, which are turned on with the opening or closing of the fire door and which can be arranged to close at the end of any desired time, depending upon the rate of driving and frequency of firing found desirable. The firing of small amounts of coal at frequent intervals produces less smoke than firing large amounts at longer intervals. The latter method, however, usually proves less tiresome to the fireman and is for that reason more frequently adopted.

Forced Draft.—The use of forced draft, as a substitute for, or as an aid to, natural chimney draft, is becoming quite common in large boiler-plants. Its advantages are that it enables a boiler to be driven to its maximum capacity to meet emergencies without reference to the

state of the weather or to the character of the coal; that the draft is independent of the temperature of the chimney gases, and that therefore lower flue temperatures may be used than with natural draft; and in many cases that it enables a poorer quality of coal to be used than is required with natural draft.

Forced draft may be obtained: First, by a steam-jet in the chimney, as in locomotives and steam fire-engines; second, by a steam-jet blower under the grate-bars; third, by a fan-blower delivering air under the grate-bars, the ash-pit doors being closed; fourth, by a fan-blower delivering air into a closed fireroom, as in the "closed stokehold" system used in some ocean-going vessels; and fifth, by a fan placed in the flue or chimney drawing the gases of combustion from the boilers, commonly called the induced-draft system. Which one of these several systems should be adopted in any special case will usually depend on local conditions. The steam-jet has the advantage of lightness and compactness of apparatus, and is therefore most suitable for locomotives and steam fire-engines, but it also is the most wasteful of steam, and therefore should not be used when a fan-blower system is available, except for occasional or temporary use, or when very cheap fuel, such as anthracite culm at the coal-mines, is used.

The closed stokehold system has as yet been used only in marine practice, where it has some advantage, such as ventilation of the fireroom, over the closed ash-pit system. Induced draft has been used to some extent on land, with good results, but it does not appear to have any especial advantage over the closed ash-pit system, except convenience of application in some situations, as where an exhaust-fan can be placed in the chimney more easily than a fan-blower of sufficient size can be accommodated in the boiler- or engine-room. In a crowded and poorly ventilated fire-room a fan-blower delivering air under the grates and maintaining a pressure of gas in the furnace may sometimes cause objectionable gases and dust to issue into the fireroom, and in such a case induced draft may be preferable.

When an economizer is used to absorb some of the heat escaping from the boilers, it is generally advisable to use forced draft, since the lower temperature of the gases discharged from the economizer reduces the force of draft in the chimney, and the friction of the gas passages through the economizer itself reduces the force of draft at the boiler.

Forced draft is especially valuable in large boiler-plants, such as those of electric light and power stations, where the demand for steam is much greater during a few hours in the day than during the rest

of the time. A boiler-plant which would be insufficient with natural draft to supply the steam required during the hours of heaviest load, may be able to supply it with ease by the aid of forced draft.

When forced draft is used, it is advisable to provide it with automatic regulation, the delivery of steam to the engine driving the fan being regulated by a reducing- valve, or a cut-off valve, controlled by the pressure in the boiler, as in the Beckman system. This system consists of a fan-blower, driven by a small engine, delivering air into a conduit built under the bridge wall, which conduit may be common to a battery of boilers, and thence through openings into the ash-pit under the grate of each boiler. In the steam-pipe leading to the engine there are three valves. The first automatically opens or closes as the steam-pressure falls or rises. The second is a reducing-valve which delivers to the engine steam of the pressure required to drive the engine at the right speed for furnishing the air to burn the particular kind of fuel used. The third is a by-pass valve which lets enough steam into the engine while the first valve is closed to keep the engine just moving and furnishing enough air to keep the grates cool. The damper leading from the air-conduit into the ash-pit is closed when the boiler is out of use or during cleaning.

The Effect of Damper Regulation.—To obtain maximum economy of a steam boiler during a test at a given rate of driving it is important that the rate be kept as nearly constant as possible. If it is allowed to fluctuate there will be a difficulty in adusting the air supply and the thickness of the bed of coal so as always to have the best furnace conditions. If, therefore, the demand for steam from the boiler plant varies, assuming there are other boilers in it besides the one being tested, it is well to let the fluctuations be taken care of by the other boilers, checking their draft or closing their dampers when the pressure rises and increasing their draft when it fails, so that the boiler under test may continue to be driven at a steady rate. In regular practice, however, it is customary to take care of the fluctuations in the steam demand and supply by means of a damper regulator which controls the draft in the main flue, or in the case of forced draft by a regulator that controls the rate of driving of the fan or blower.

Draft Loss through a Vertical Pass Water-tube Boiler.—(T. A. Marsh, *Indust. Eng.*, July, 1912.)

Draft in furnace	0.50 in.	
Draft above first row of tubes, front upward pass	0.53	0.05 loss
Draft above twelfth row of tubes, front upward pass	0.58	
Draft above twelfth row of tubes, middle downward pass	0.62	0.20 loss
Draft above first row of tubes, middle downward pass	0.82	
Draft above first row of tubes, rear upward pass	0.85	0.13 loss
Draft above twelfth row of tubes, rear upward pass	0.98	
Draft in flue, just beyond damper	1.00	

The increase in draft loss through the second, or downward, pass is due to its restricted area, as compared with the first pass. In the third pass the temperature and volume of the gas are greatly reduced, which accounts for the draft loss being less than in the second pass.

Arrangement of Forced Draft Apparatus.—Fig. 35 illustrates the arrangement of forced draft apparatus at the power station of the Hudson & Manhattan R. R. Co. in Jersey City, N. J., which operates

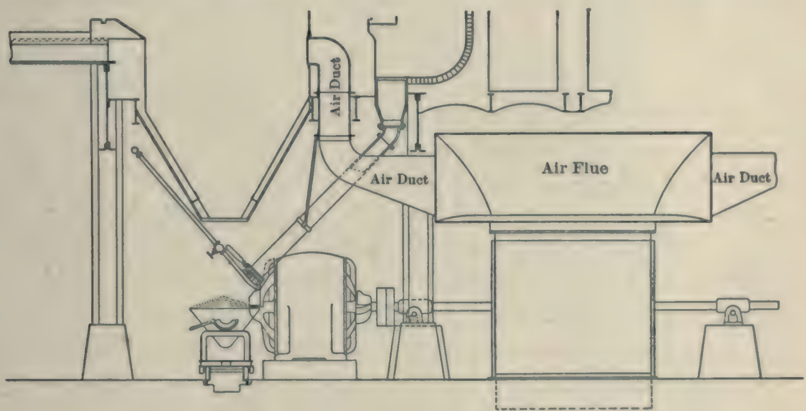


FIG. 35.—ARRANGEMENT OF FORCED DRAFT APPARATUS.

the railroad through tunnels under the Hudson river. The air flue shown serves the batteries of boilers on both sides of the boiler room. The fan is a double inlet "Sirocco," driven by a 500 H.P. electric motor, and its normal duty is 209,000 cubic feet of air per minute at 4.9 ins. water gauge.

Economy of High Rates of Driving at Peak Loads.—(H. G. Stott, *Power*, November 8, 1910.) In the boiler room the investment can be kept down by adding grate surface instead of more boilers, and by the use of forced draft the old rating of 10 sq. ft. of heating surface per boiler horsepower can safely be reduced to 4

or 5 without materially adding to the cost of boiler or furnace maintenance.

While the overall boiler efficiency will begin to fall off beyond 175 or 200 per cent of rating, the small loss thus entailed is insignificant compared to the saving in fixed charges.

The solution of the problem of carrying peak loads economically is therefore to be found in reducing the investment per kilowatt to a minimum, and this can be best accomplished at present by the use of steam turbines and by the use of large grate area, such as a ratio of 30 or 40 sq. ft. of heating surface to each square foot of grate area, instead of the present ratio of 55 or 60 to 1.

Relation of Draft to Boiler Capacity.—Fig. 36 is a plotted chart showing the furnace draft and the flue gas temperatures in eleven

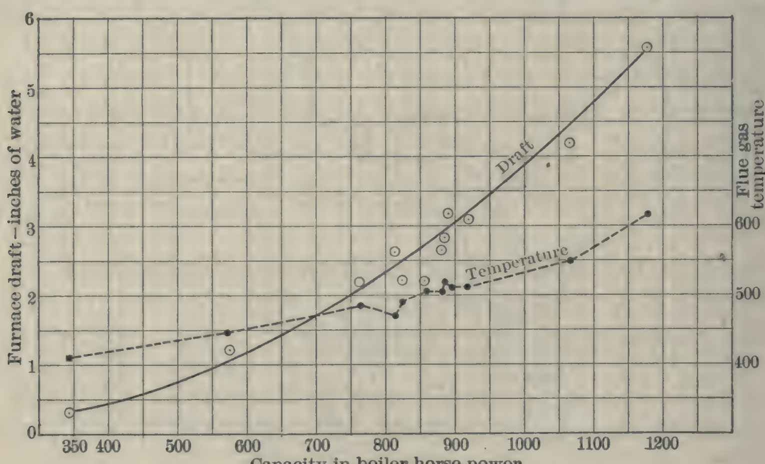


FIG. 36.—RELATION BETWEEN BOILER CAPACITY AND FURNACE DRAFT.

tests of the Green chain grate stoker. (Proc. Western Soc. of Engrs., 1912.) The draft curve shows an interesting relation between the horsepower and the draft; it is that the horsepower is nearly proportional to the square root of the draft pressure, as follows:

Draft, ins.	0.5	1	2	3	4	5
$\sqrt{D}$	0.71	1	1.41	1.73	2	2.24
H.P.	420	570	750	905	1015	1120
H.P. $\div \sqrt{D}$	590	570	532	523	508	500

If the resistance of the fuel bed, the air per pound of carbon, and the boiler efficiency were the same at all rates of driving, the

horsepower should theoretically vary directly as the square root of the draft pressure, but in fact there is usually an increased resistance at the higher rates of driving on account of increase in the thickness of the fuel bed, an increase in the volume per pound of furnace gas on account of the increased temperature of the gas between the furnace and the flue, and a decrease in efficiency, all of which will cause a decrease in the ratio $HP \div \sqrt{D}$.

The Prat Induced Draft System. (Louis Prat, Paris; Schütte & Koerting Co., Philadelphia) has been extensively introduced in Europe. Only a small portion of the gases is passed through the fan, which is therefore of relatively small bulk. The pressure produced by the fan is used in the manner of the impulse jet of an ejector to create the necessary negative pressure for the induction of the gases. The system is illustrated in Fig. 37. It includes a metal plate stack comparable to an ejector of which C is the converging portion, A the chamber and B the diffuser. The negative pressure inducing the flow of the gases is created by a fluid impulser furnished by a fan-blower and injected into the chamber by the nozzle D. In case of a stoppage of the fan the impulse is produced by an emergency steam ejector S. The fluid impulser can either be cold air taken by the fan from outside or the hot gases directly from the flue as shown in the illustration.

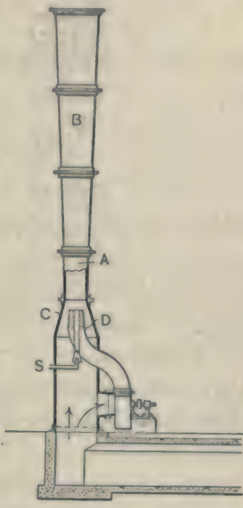


Fig. 37.—Prat Induced Draft System.

The Howden Hot-air System.—In 1884 James Howden applied to the boilers of the *City of New York* a forced draft apparatus in which the air-supply was heated by being circulated around a series of tubes, through which the hot flue-gases passed on their way to the stack. In this system part of the hot air is delivered into the ash-pit, and part above the bed of coal in the furnace. The system has been extensively adopted in marine practice. Among the advantages claimed for it are: 1. Part of the heat which would otherwise escape in the flue-gases is returned to the boiler. 2. By whatever amount the air for combustion is increased in temperature by the waste gases, the average temperature of the furnaces is practically raised to the same extent. If, say 200° is added to the air of combustion by the air-heat-

ers, the average temperature of the furnaces is raised 200°, and the evaporative power of the heating surface is thereby increased. 3. The gases from the burning fuel combine more readily with the oxygen of the air of combustion as the temperature of the fire increases.

Retarders.—In connection with the Howden system, spiral strips of metal, shown in Fig. 38, are placed in the tubes of the boiler.

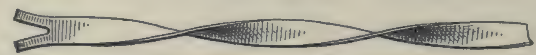


FIG. 38.—A RETARDER.

These compel the gases to take a spiral motion in passing through the tubes, causing them to come more directly in contact with the surface of the tubes, and by conducting heat through the metal of the retarder into the metal of the tubes, increasing their efficiency.

Results of tests of a horizontal fire-tube boiler with and without retarders are given in a paper by J. M. Whitham in Trans. A. S. M. E., vol. xvii. p. 450. Among his conclusions are the following:

1. Retarders show an economic advantage when the boiler is pushed, varing in the tests from 3 to 18 per cent.

2. Retarders should not be used when boilers are run very gently and when the stack-draft is small.

The Ellis & Eaves Hot-air System is similar to Howden's, but the draft is produced by a fan placed at the base of the funnel. The air is heated by being passed through the tubes in the heater, while the hot gas circulates around them. Both the Howlen and the Ellis & Eaves systems are illustrated and discussed at length in Bertin & Robertson on "Marine Boilers."

An extensive series of experiments on the use of warm blast was made by J. C. Hoadley in 1881, and described at great length in Trans. Am. Soc. M. E., vol. vi. p. 676. The results, according to Mr. Hoadley, showed a possible net saving of from 10 to 18 per cent over the best attainable practice with natural chimney draft and air at ordinary atmospheric temperatures. Notwithstanding these results, the warm-blast system has not as yet made any headway in land practice.

Calculations for Forced Draft.—In designing a forced draft installation the principal data needed are: 1, The maximum number of pounds of coal that will have to be burned per hour at the most rapid rate of driving, when the efficiency of the boiler, furnace

and grate is lowest; 2, the number of pounds of air per pound of coal.

A pure coal consisting of 95 per cent C, 5 per cent H would require for complete combustion, theoretically, per pound of coal,

$34.56\left(\frac{C}{3} + H - \frac{O}{8}\right)$	12.672 lbs. air
Add 50% in order to insure that all the C is burned to CO_2	6.356 " "
	19.008 " "
Add another 50% for emergencies and for unskillful firing. (This may be omitted if mechanical stokers and CO_2 apparatus are used.)	6.336 " "
	25.344 " "

Or say 25 pounds of air per pound of combustible. Multiplying this figure by the ratio of combustible to total coal (including ash and moisture) in the coal to be used gives the number of pounds of air per pound of coal. Thus, if the sum of moisture and ash in a given coal is 20 per cent, and the combustible 80 per cent, then $0.80 \times 25 = 20$ is the number of pounds of air required per pound of coal. This may be reduced to 15 pounds in large plants in which mechanical stokers are used and the firing is controlled so as to avoid excessive air supply, by means of gas analysis or CO_2 apparatus.

Multiplying the figures given above by 13.342, the number of cubic feet per pound of air at 70° F., gives the cubic feet of air per pound combustible = 254 cubic feet for 50 per cent excess air, or 338 cubic feet for 100 per cent excess.

It is common to figure the air supply as a factor of the boiler horsepower to be developed. The method of making the calculation with different kinds of fuel is shown in the table on page 242.

These figures are based on actual boiler horsepower to be developed (1 H.P. = 34.5 pounds water evaporated from and at 212° per hour) and not upon the "rating" of the boiler. In modern electric power plants it is not uncommon to drive the boilers during the time of "peak loads" to from two to three times their nominal rating, which is usually based on 10 square feet of heating surface per horsepower.

For induced draft the figures of cubic feet of air per minute given

ANALYSIS OF COMBUSTIBLE IN COAL

Kind of Coal.	Anthracite.	Semi-bit.	Eastern Bit.	Western Bit.	Lignite.	Oil.
H	3.16	4.76	5.03	5.41	5.05	13
C	92.20	90.70	84.[illegible]	80.93	73.21	85
O	2.72	2.81	7[illegible]	11.18	18.65	2
N	0.98	1.13	1.[illegible]4	1.61	1.47	
S	0.94	0.60	1.00	0.87	1.62	

LBS. AIR PER LB. COMBUSTIBLE = $34.56(C/3+H-O/8)$, WITH NO EXCESS AIR.

11.59	11.97	11.20	10.71	9.37	14.20

B.T.U. PER LB. COMBUSTIBLE.

15,000	15,800	15,200	14,400	12,800	19,000

BOILER EFFICIENCY, ESTIMATED.

0.75	0.75	0.75	0.70	0.60	0.75

B.T.U. UTILIZED PER LB. COMBUSTIBLE.

11,250	11,850	11,400	10,080	7,680	14,250

LBS. COMBUSTIBLE PER HOUR PER BOILER H.P. (1 H.P. = 33,479 B.T.U. PER HOUR.)

2.98	2.83	2.94	3.32	4.36	2.35

LBS. AIR PER BOILER H.P. HOUR, ASSUMING NO EXCESS AIR.

34.54	33.88	32.93	35.56	40.85	33.37

CU.FT. OF AIR PER MINUTE AT 70° F. PER BOILER H.P. (1 LB. AIR = 13.342 CU.FT.)

No excess air..	7.682	7.535	7.323	7.909	9.085	7.422
50% " "	11.52	11.30	10.99	11.86	13.63	11.13
100% " "	15.36	15.07	14.65	15.82	16.17	14.84

above are multiplied by the ratio of the absolute temperature of the gas to be handled by the fan to the absolute temperature corresponding to 70° F., or by $\frac{T+460}{530}$, in which T is the temperature of the gas in Fahrenheit degrees, to obtain the number of cubic feet of hot gas per minute.

For T =	250°	300°	350°	400°	450°	500°	550°	600°	650
Ratio $(T+460)/530$	1.340	1.434	1.528	1.623	1.717	1.811	1.906	2	2.094

The American Blower Co. furnishes the following as the basis for calculation for mechanical draft:

MECHANICAL DRAFT IN STATIONARY WORK.

Induced Draft.

Cu. ft. per min. required: 36 cu. ft. per min. per boiler horsepower per hour at 550° F.

Suction required: For rat capacity 1 in. water gauge, static essure; for 25% overload 1¼ in.; for 50% overload 1¾ in.

Gases handled: 482.7 cu. ft. at 550° F. per lb. coal burned.

Forced Draft.

Cu. ft. per min. required: 28 cu. ft. per min. at 70° per boiler horsepower with chain grates; 21 cu. ft. with ordinary grates; 18 cu. ft. with underfeed stokers.

Pressure required: Stokers, 2.5 in. water gauge, static, not including duct friction.

Ordinary grates: 1.5 in. water gauge, static, but allowance of sufficient power to speed up to 1¾ in.

Where the fan blows directly into the ash pit without ducts 1.25 in. static water gauge will not be exceeded with ordinary rate of coal combustion.

Air handled: 253.5 cu. ft. at 70° F. per lb. coal burned.

MECHANICAL DRAFT IN MARINE WORK.

Induced Draft (Ellis & Eaves system).

Cu. ft. per min. required: 8.05 cu. ft. per min. at 550° per lb. coal burned per hour.

Suction required: 1¼ to 1½ in. water gauge (negative pressure).

Gases handled: 482.7 cu. ft. at 550° F. per lb. coal burned.

Forced Draft (Howden system).

Cu. ft. per min. required: 4.2 cu. ft. per min. at 70° F. per lb. coal burned per hour.

Pressure required at fan: 2½ to 3 in. water gauge (static pressure).

Air handled: 253.5 cu. ft. at 70° F. per lb. coal burned.

The Buffalo Forge Co. in its Engineers' Hand Book, p. 85, gives the following:

It is customary in practice in selecting apparatus for mechanical draft purposes to allow for 100 per cent excess air for hand-fired boilers, or 16.70 cubic feet of air per minute at 70° per boiler H.P. for a forced draft fan, and 32.40 cubic feet per minute at 550° for an induced draft fan. An allowance of 50 per cent excess air is made where the boiler is equipped with a stoker, or 11.70 cubic feet per minute at 70° per boiler H.P. for a forced, and 22.80 cubic feet per minute at 550° for an induced draft fan.

The statement made in the catalogues of some fan manufacturers to the effect that with forced draft less air is used per pound of coal than with chimney draft, and that, therefore, with forced draft there is a higher temperature in the furnace and less loss of heat in the flue gases, is erroneous. With forced draft it is possible to make a greater difference in pressure between the ash pit and the combustion chamber than with ordinary chimney draft, and this would tend to increase the air supply rather than to diminish it if the thickness of the fire bed were not increased to counteract this effect. With either forced draft or chimney draft it is equally easy to reduce the air supply to 18 pounds per pound of coal, notwithstanding the following statement which has been reprinted for many years without reference to any authority:

> Experiments made by the United States Navy have demonstrated that in the ordinary hand-fired furnace with stack draft about twice the theoretical quantity of air is required, or about 24 pounds of air per pound of bituminous coal.

When the number of cubic feet per minute and the total difference in pressure between the fan and the combustion chamber are determined or estimated for the maximum rate of driving, then a selection of the fan to be used is made, referring to the tables of size, capacity, speed, pressure, and power, which are published in the catalogues of fan manufacturers. The American Blower Co. gives the following:

> The requirements of a given installation can usually be met by several sizes of fans, and the final choosing of the fan will depend upon whether initial cost, the cost of power, or space, is most important. The following examples will illustrate the variation in the sizes of "Sirocco" fans for a given duty. Assume that the installation requires 66,000 cubic feet of air per minute at 1½ inches water gauge static pressure, and that the tip speed of the fan wheel shall not exceed 3500 feet per minute. Referring to the capacity tables the following performances will be found:

Single inlet fan No	14	13	12
Cubic feet per minute	66,000	67,000	65,500
Revolutions per minute	155	170	190
Tip speed, feet per minute	3,410	3,480	3,590
Brake horse-power	27.9	29.5	31.4
Diam. of wheel, ins	84	78	72
Width of wheel, ins	42	39	36

If power consumption is the controlling feature, the No. 14 fan would be the choice; if initial cost or space limitation determines the selection, the No. 13 fan. As the tip speed of the No. 12 fan slightly exceeds the specified amount, it cannot be considered.

Furnaces for Burning Coal-dust.—Fig. 39 shows a coal-dust stoker patented in 1895 by F. De Camp of Berlin, Germany. The

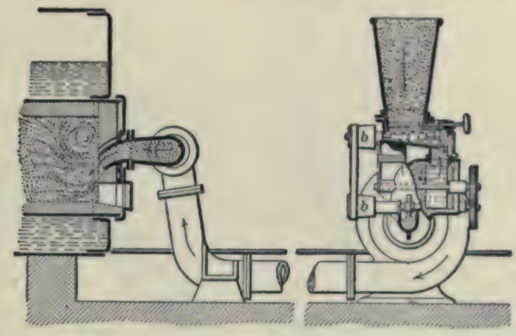


FIG. 39.—METHOD OF BURNING COAL-DUST.

coal is ground in a mill and carried to the hopper of the stoker by a travelling conveyor, from which it is delivered into the furnace by a fan-blast. The quantity of coal-dust as well as the quantity of air blown into the furnace is regulated by slides. The advantages claimed for the apparatus are that it is an automatic stoker and forced-draft system combined, and that the combustion is complete and smokeless.

The objections are, the cost of power for grinding the coal into a fine powder and for driving the fan, together with the extra labor required to keep the flues clean, on account of the large accumulation of ash and partially burned coal-dust which is carried over by the blast.

The Wegener Apparatus for Burning Powdered Coal.—Fig. 40 shows an apparatus for burning powdered coal, invented by Carl Wegener, and first used in Germany in 1892. It is described as follows:

Coal ground so that it will pass through a sieve of 125 meshes per linear inch is fed into the hopper, whence it falls on to a fine sieve

about $5\frac{1}{2}$ in. diameter. The sieve is tapped from 150 to 250 times a minute, in order to cause the coal to fall through it regularly, by means of a knocker on a vertical shaft driven by a wheel placed in the path of the entering air-supply. The air ascending in the inlet-pipe, as shown in the cut, meets the descending shower of

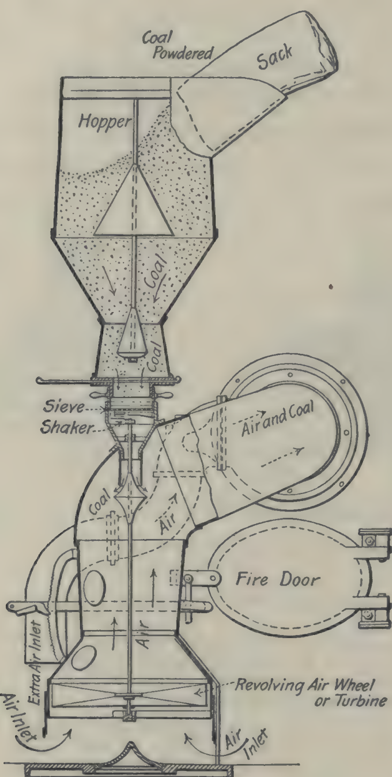


FIG. 40.—WEGENER'S POWDERED COAL APPARATUS.

powdered coal, mixes with it, and carries it into the furnace. If the air-supply is sufficient, smokeless combustion will result.

Records of tests of the Wegener apparatus* indicate that it does not give any higher economy than can be obtained by mechanical stokers, or other means of burning soft coal, which do not require the coal to be powdered.

* *Engineering News*, Sept. 16, 1897.

Fig. 41 is an illustration of a coal-dust feeding apparatus built by C. O. Bartlett & Snow Co., Cleveland, O. (*The Engineer*, Chicago, April 1, 1904). The coal dust is fed from a storage bin into the hopper *A*, from which it is conveyed by the feed-worm *B* and spout *F* to the air spout *D* through which it is blown into the cast-iron spout *G* leading to the furnace. The speed of the feed-worm is adjusted by changing the position of the friction wheel *I* on the plate *H*. The air furnished by the fan *C* is controlled by a valve *E*. A test of this apparatus with pulverized coal from Illinois screenings, 40-mesh fine, containing 3.5 per cent moisture and 17.5 per cent ash, with a water-tube boiler rated at 280 H.P. developed 254 H.P. or 90.7 per cent of rating, and an equivalent evaporation of 9.132 lbs.

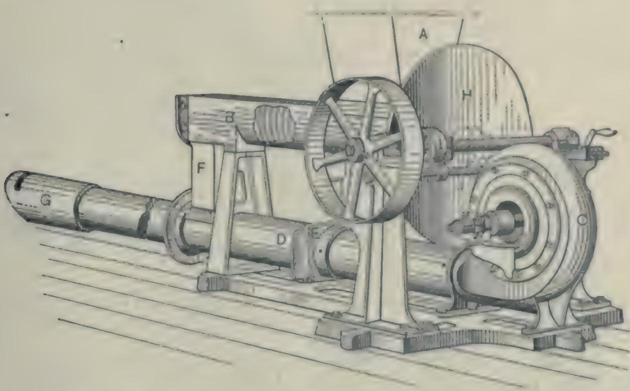


FIG. 41.—COAL-DUST FEEDING APPARATUS.

per lb. of combustible. Taking the heating value of Illinois coal at 14,000 B. T. U. per lb. of combustible, the efficiency is 63.2 per cent. A much higher result than this can be obtained with a Dutch-oven furnace and a mechanical stoker.

The conditions of successful operation with dust fuel are stated as follows (*The Engineer*, Jan. 1, 1903):

First, the coal must be of uniform size before perfect combustion can be had; second, the coal should contain a uniform percentage of moisture; in other words, the same results are not obtained when burning coals containing different degrees of moisture. Third, powdered coal should be burnt in suspension in air. If the fuel is swept or pushed into the furnace, the heavy particles fall to the bottom and become solid clinker, which is very objectionable and almost impossible to get out of the furnace.

Illustrated descriptions of several other forms of apparatus for burning pulverized coal will be found in a "Symposium on Powdered Fuel" in *Journal, A. S. M. E.,* Oct. 1914.

Method of Burning Petroleum.*—The simplest and best way of burning liquid fuel is by injecting it in the form of spray by means of a jet of steam into the furnace and allowing the right amount of air to mix with it.† The number of different injectors or burners that have been devised for this purpose is legion.

The simplest device would consist of two tubes fastened together, as shown in the annexed sketch, Fig. 42. In this, 1 is the oil feed-pipe; 2, a cock for regulating supply of oil; 3, the steam pipe; 4, the valve for regulating supply of steam; 5, a guard around pipe preventing overflow. The lower tube is flattened out to a thin, broad opening, from which the stream of air or steam issues under pressure. The upper tube allows a stream of oil

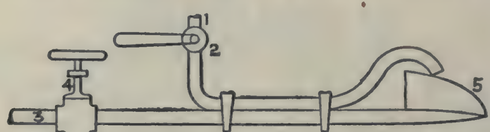


FIG. 42.—PETROLEUM BURNER.

to flow from the supply tank, this flow being regulated by the supply cock. The oil is conducted by the guard, 5, which prevents it flowing over the sides of the lower steam-pipe, and distributes it in a thin sheet over the rapidly issuing steam, with the result that the oil is rapidly carried forward in the form of a finely divided spray, which is the next thing to gas, and ignites almost as easily. By changing the shape of the issuing jet of steam, different shapes may be given to the flame. If we give the steam-jet a fan-shaped opening, the greater part of the oil will be delivered at the sides and we will have a wide and short flame. If, on the contrary, we desire a long, narrow flame, we give the steam-jet a concave opening, then most of the oil is delivered on the center of the steam-jet and is propelled forward to a considerable distance.

Those who try to improve the efficiency of a fuel by altering the burner resemble a man who seeks to improve the steaming of his boiler by changing the injector. The place to work at and improve is inside the fire-box or combustion-chamber. The oil fuel must be so broken up or pulverized as to allow of its mixing with the air and

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* Extracts from a paper by H. Tweddle, in *The Engineering and Mining Journal,* Oct. 21, 1899.

† Spraying or atomizing either by the use of a jet of air at high pressure or by mechanical means is now generally admitted to be better than spraying by means of a steam jet.

being instantly consumed. If it is not consumed in the fire-box, it issues either in the form of smoke or of foul-smelling, unburned gases, and fuel is wasted.

If we take a vessel filled with benzine and set fire to it, it burns with a heavy flame, and large quantities of black smoke are given off. As no air can get to the interior portion, combustion takes place on the outside, and as the contained hydrogen has a greater affinity for oxygen than carbon has, it combines with most of the oxygen furnished

FIG. 43.—IMPERFECT COMBUSTION.
(Fire at the Standard Oil Works, Bayonne, N. J., July 5, 1900.)

by the air, the carbon is set free and is visible in the form of a heavy, black smoke. (See Fig. 43.)

If we admit air to the interior of the volatile gases which are being given off, more oxygen is supplied and part of the carbon burns and the smoke diminishes, and if arrangements are made so as to admit sufficient air to all parts of the benzine and its vapor, then we will have complete combustion and no smoke will be given off.

In order to obtain the greatest efficiency from fuel oil, it should be burned in a fire-brick combustion-chamber, so as to obtain the very

highest possible temperature. Notwithstanding the fact that a certain amount of heating surface is covered by the brickwork, experiments have shown that there is both an increase in evaporation and a saving in fuel with the lined fire-box.

Imperfect Combustion of Oil.—Fig. 43, reproduced from a photograph of a fire at the refinery of the Standard Oil Co. at Bayonne, N. J., gives an idea of the amount of smoke that may be made by burning oil. The column of smoke went up at an angle to a height of perhaps half a mile, and then traveled horizontally over five miles before it was dissipated into the surrounding atmosphere.

Use of Petroleum in Locomotives.—Mr. Tweddle describes the use of petroleum as fuel for locomotives on the Oroya Railroad, in Peru, where he introduced it in 1890. Two locomotives, exactly alike in all other respects, were tested, one with coal and the other with oil. They were American Rogers engines, Mogul type, with 47 in. drivers; cylinders 18×24 in.; weight of engine 38 tons, tender 28 tons; five cars averaging 18 tons each. The grades were as high as 4.2 per cent, or 1 in 27, with some sharp curves. The average consumption of coal for a month was 79.30 lbs. per train mile, and that of oil 38.55 lbs., or less than half.

The arrangement for the interior of the fire-box is shown in Fig. 44. No alterations were made in the fire-box, while but few additions

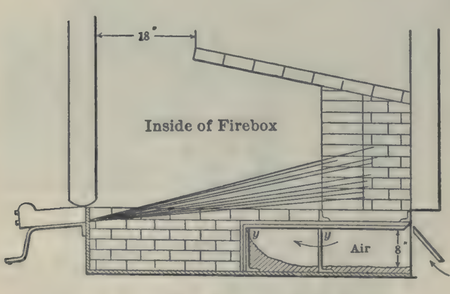

Fig. 44.—Petroleum Furnace.

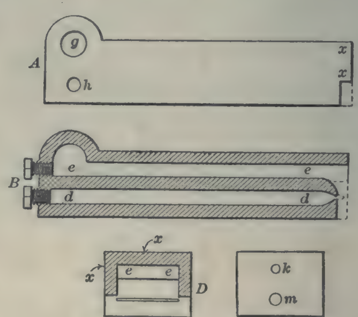

Fig. 45.—Oil Burner.

were made to the regular ash-pan. The back damper was completely closed, a large front damper with about 2 sq. ft. superficial opening being arranged in front. A plate with an air-opening 20 × 14 in. supported the fire-brick at the back of the fire-box, which receives the vaporized oil.

In Fig. 45, the burner is represented. *A* is a general side view of burner; at *g* it is tapped for a $1\frac{1}{4}$-in. oil-pipe, and at *h* for a $\frac{1}{2}$-in.

steam-pipe. In the sectional view, *e e* is the oil-passage, *d d* is the steam-passage; both these passages being 3 by $\frac{3}{4}$ in. *D* represents the front end of the burner, and *E* represents the back end of the burner.

The oil coming through the passage, *e e*, falls directly on the steam shooting through the narrow slit at the end of the passage, *d d*, and is completely atomized.

With this burner the bricks do not serve in any way for breaking up the oil, but merely as a white-hot retort in which air and vaporized oil are mixed in the proper proportions.

The supply of air is regulated by the front damper, the supply of oil by a wheel-valve worked by the fireman's hand in the cab. The steam is seldom touched except when an engine is lying up for any length of time at a station. With the oil and air under such easy control there is no difficulty in obtaining perfect combustion without smoke.

The holes at the back of the burner are closed with plugs. By unscrewing these the burner can be quickly cleaned without removing; this, however, is rarely necessary, the burner, as a rule, keeping perfectly clean for an indefinite period.

The burner is cast in one piece and finished by hand. The length of the burner is entirely arbitrary. The width is made to suit the quantity of fuel to be introduced.

On the heavy grades of the Oroya line, as much as 220 lbs. of coal are burned per mile, or 110 lbs. of oil. To perfectly spray such a large flow of oil, a certain width of passage is necessary. The burner best adapted to such heavy work had an oil-passage 3 in. wide and a steam-outlet of $3\frac{1}{4}$ in. The oil-aperture was 3 by $\frac{3}{4}$ in., the steam-aperture $3\frac{1}{4}$ by 1-40 in.

Around the oil-opening runs a sort of projecting hood which prevents any oil from leaking when rounding sharp curves. Steam from another locomotive is used in getting up steam; 100 lbs. pressure from cold water has been shown on the steam-gauge in 25 minutes, but an hour is generally taken, so as not to strain the boiler. If necessary wood can be used to raise steam.

The oil-fired engine, after running six months, showed no signs of leaking or straining. About 150 fire-brick were used for the whole brickwork, including the arch. This brickwork lasts from six to eight months.

The Hammel Oil Burner, which has been extensively used in California is shown in Fig. 46. It is similar in principle to the one described by Mr. Tweddle.

The Urquhart Oil Burner, used in locomotives in Russia, is shown in Fig. 47. The oil runs down a pipe, which ends in the external nozzle of the injector, while the steam passes through the inner nozzle, which it enters through a ring of holes, the steam- and oil-cavities

being separated by a stuffing-box packed with asbestos. This packing is renewed once a month. The steam-supply is regulated by a valve, and the oil-supply by screwing the steam-nozzle backward and forward in the external nozzle, thus varying the section of the annular

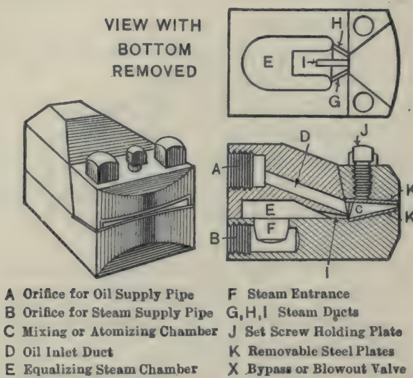

FIG. 46.—THE HAMMEL OIL BURNER.

passage. This is effected by a worm and worm-wheel, the latter of which is connected to the steam-nozzle by a feather-key, while the former is on a shaft which terminates in a position conveniently acces-

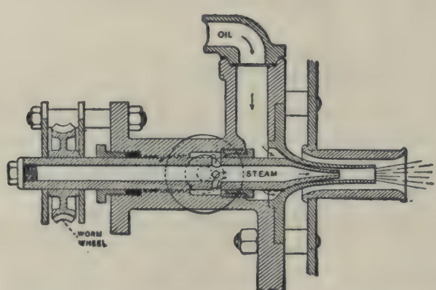

FIG. 47.—THE URQUHART OIL BURNER.

sible to the fireman. The injector is entirely outside of the fire-box, so that the carbonizing of the oil at the nozzle is reduced to a minimum. The blast of oil and steam is delivered into the furnace through a tube into which the nose of the injector projects, and through which a supply of air is also drawn by the action of the jet.

The amount of steam required to operate the injector on the Russian railway, according to Mr. Urquhart, is from 8 to 13 per

cent of the steam made by the boiler, the highest percentage being required in winter.

A fuel-oil burner using oil at high pressure and air at low pressure, designed by H. B. Stilz, Philadelphia, is shown in Fig. 48.

This design comprises an inner nozzle through which oil is forced at 50 pounds pressure. Near the small orifice and within the

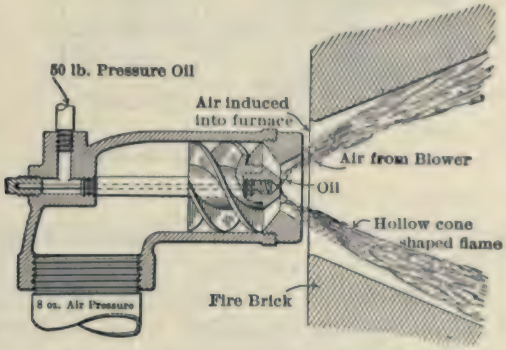

FIG. 48.—HIGH-PRESSURE OIL BURNER.

passage is placed a spindle bearing a spiral fin, which causes the oil on delivery to rotate and spread out in a cone-shaped film. Around the inner nozzle is a casing through which air passes, and a spiral fin gives the air a whirling motion as it passes out.

Mechanical Oil Burners. (E. H. Peabody, Proc. Soc. Nav. Engrs. and Marine Archts., 1912).—A "mechanical atomizer" is one which uses pressure alone, without steam or compressed air for spraying the oil. In the types in successful use the oil is given a whirling motion inside of the burner tip, either by forcing the oil through a passage of helical form, as in Howden's burner, Fig. 49, or by de-

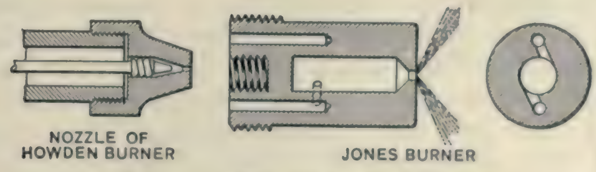

FIG. 49.—MECHANICAL OIL BURNERS.

livering the air tangentially to a circular chamber from which there is a central outlet, as in the Jones burner, or by a combination of

both methods. The Peabody burner, Fig. 50, is of the tangential type; in it oil is delivered under pressure to an annular channel cut in the face of a nozzle upon which is screwed a tip having a very small central chamber communicating with a discharge orifice. Between

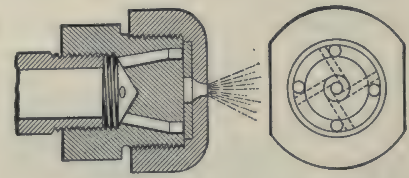

FIG. 50.—PEABODY OIL BURNER.

the nozzle and the tip a thin disc is inserted which has a hole in the center of the same diameter as that of the central chamber of the tip, and small slots or ducts extending tangentially from the edges of the central opening outward to the annular channel in the nozzle so as to put it in communication with the central chamber. The atomized particles of oil fly off from the orifice in straight lines under the action of centrifugal force, thus forming a hollow conical spray. A good burner will atomize moderately heavy oil with an oil pressure as low as 30 lbs. and from that up to 200 or above. If this range is insufficient to meet the variable steam requirements, it is better to shut down a portion of the burners entirely than to attempt to adjust each individual burner separately. The air supply can easily be controlled for all burners by regulating the draft pressure, and the air can be closed off entirely when a burner is shut down. Another means of varying the quantity of oil delivered by all burners in addition to alteration of oil-pressure is alteration of oil temperature. Generally speaking, under working conditions any increase in temperature of the oil results in decreased capacity of the burners, the pressure remaining the same. The reverse is the case at low temperatures, the critical point depending on the relationship between viscosity and specific volume of the oil in question.

Mr. Peabody gives a chart showing the capacity of a round flame burner with Texas crude oil of 18° Baumé, under 200 lbs. pressure, at different temperatures, from which the following figures are taken:

Temp., deg. F...	80	90	100	110	120	130	140	160	200	240
Lbs. oil per hr...	350	410	430	440	430	400	370	345	310	275

Furnace Used with Oil Burners.—Having an atomizer that will produce a fine spray with heavy oil, the next problem is one of furnace design. This is satisfactorily solved with the Babcock & Wilcox marine boiler furnace, the characteristics of which, as described by Mr. Peabody, are: Large volume in proportion to the heating surface of the boiler; upward slope of the roof toward the rear, resulting in increase of height and volume in the direction of the entering oil spray and thus providing for the expansion and diffusion of the gases; small amount of boiler heating surface exposed, and, on the contrary, large exposed surface of incandescent refractory material, thus tending to maintain high furnace temperature and promote complete combustion of the oil; tubes almost parallel with the path of the oil spray injected into the furnace from the front, thus promoting proper distribution of the gases along the tubes and preventing local overheating; outlet from the furnace at the point most remote from the location of the atomizers, thus insuring long travel of the gases; and, finally, means for bringing the heated products of combustion into the closest possible contact with the entire heating surface of the boiler, discharging the waste gases into the uptake at temperatures but little above that of the steam generated.

Experiments with Oil Burning.—With the atomizers and furnace above described, much experimenting was necessary to determine the best form and dimensions of apparatus for admitting and distributing air. Great delicacy is required in introducing the air for combustion, very slight changes affecting the results in unsuspected ways, and while almost any method may result in smokeless combustion, maximum economy and capacity can only be secured by careful and intelligent design. It is not necessary to give the air a whirling motion, but, judging from rather exhaustive experiments, better gas analyses are secured, lower air pressures are required, and less refinement of adjustment is needed if the air is brought into contact with the air supply with the right sort of twist. The impeller plate shown in Fig. 51 gave the most satisfactory results. They are 8 in. diameter, set in cast-iron boxes in the furnace front. The nozzle of the burner is set about 1 in. outside of the plane of the central opening. Results of tests of a marine boiler with the Peabody burner will be found in the chapter on Boiler Performance.

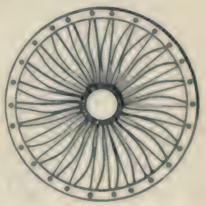

Fig. 51.—Impeller Plate.

Using Oil and Coal Conjointly. (H. A. Wagner, *Power,* June 20, 1911).—The load on the Westport station of the Consolidated Gas, Electric Light and Power Company of Baltimore has well defined peaks of comparatively short duration, and these considerations led to experiments with fuel oil for supplementing the coal fires and obtaining the desired increase in boiler output.

After trying several settings the furnace arrangement shown in Fig. 52 was finally adopted. The space back of the usual coal grate

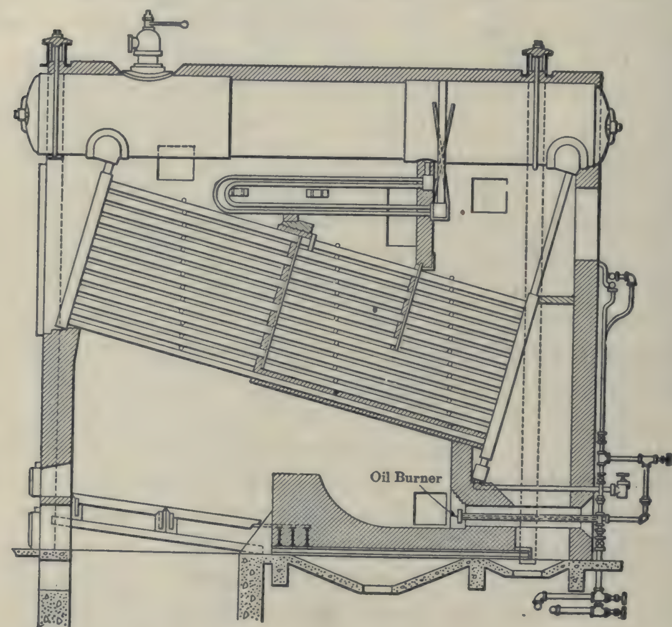

FIG. 52.—FURNACE FOR BURNING COAL AND OIL.

is made into a large combustion-chamber with the oil burners at the extreme rear end. This combustion-chamber is separated from the boiler tubes above it by tiling and from the coal grate by a low bridge-wall. By this arrangement either oil or coal or both together may be used to fire the boiler. One of the four burners in each furnace is used as a pilot and for the equivalent of a banked coal fire for keeping the boiler ready to steam. Boiler tests with this arrangement have shown approximately the following results for maximum boiler output during seven-hour runs:

Coal alone	1188 H.P.
Oil alone	702 H.P.
Coal and oil together	1445 H.P.
Coal and oil maximum, one hour	1632 H.P.

Under actual operating conditions, however, the gain by the use of oil is more marked. It has been found that 2000 KW. of station load can be carried by each boiler when using coal and oil together, with as much ease and certainty as 1200 KW. per boiler can be carried by coal alone. This shows, under operating conditions, a gain in capacity of 66% by the use of oil, or a saving of 40% in the cost of the boiler plant for a given capacity.

Tests have shown that a cold furnace, with water in the boiler at 142° F., could be made to steam at 175 lbs. pressure in 25 minutes with oil fuel as compared with 42 minutes with coal.

The cost of fuel oil at Baltimore is 43% more than coal, per heat unit, but in spite of this difference the actual cost of "banking" is less with oil than with coal, for the reason that the oil is burned efficiently while the coal is necessarily burned very inefficiently.

Practical Considerations in Oil-burning.*—Heating of the oil is an aid to economical combustion, and should take place as near the furnace as possible and be carried as high as safety permits, but not so high as to cause the oil to decompose and carbon to be deposited in the supply pipes. If preliminary heating is limited to the temperature of the flash point of the oil used, there can be no trouble from these causes.

In oil burning, the principal work of the fireman is to see that the oil pump is kept in constant operation, and that the burners do not become clogged with small particles of foreign matter, scale, etc., especially when the installation is new. Strainers of proper design, introduced on the suction line to the pump and also between the pump and the burner, will reduce this trouble to a minimum. Burners should be so installed that they can be easily disconnected from the piping and taken from the furnace for the removal of any foreign substance from their restricted orifices.

One of the most important questions in the combustion of liquid fuel is the regulation of the air supply in such a way as to obtain perfect combustion before the gases come in contact with the heating surfaces of the boiler. This is usually accomplished by hand regulation of the damper when considerable variations in the load take place, supplemented by changing the position of the ashpit doors, which are kept partly closed until a slight tendency to make smoke

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* From a paper by B. R. T. Collins, Trans. A. S. M. E., 1911.

is noticed in the furnace, when they are opened until this tendency disappears; or, better, by using an Orsat or continuous CO_2 gas analyzer to determine the position of damper and ashpit doors which gives most complete combustion.

The important features which should be embodied in all burners are: easy method of installation, construction that will allow quick inspection, easy removal of all foreign material which may clog the burner at any point, and rapid and cheap renewal of any parts which are subject to wear.

The success of an oil-fuel installation depends not so much on the type of burner or atomizer used as on the method of its installation, and the intelligence with which it is operated.

To conform with the underwriters' requirements, storage tanks above the surface of the ground should be placed at least 200 ft. from inflammable property, and the top of the tanks should be located below the level of the lowest pipe used in connection with the apparatus. When the tanks are located underground they should be outside the building, at least 2 ft. below the surface and 30 ft. from any building, with the top of the tanks below the lowest pipe in the building used in connection with the apparatus. In small and medium-sized installations, steel tanks coated with tar, having a capacity of 8500 to 15,000 gallons each, are generally used. In larger installations, reinforced-concrete tanks, generally rectangular in shape, are used. These are usually made with a partition in the center, so that any sediment or thick material may be periodically cleaned out without interfering with the continuous supply of fuel. The capacity of the storage tanks may vary from a supply sufficient for two weeks, when the oil is near at hand, and more may be obtained on one day's notice, to a supply sufficient for two or three months when the source of supply is at a considerable distance and delivery is in large quantities at irregular intervals.

Storage tanks should be fitted with vent pipes, indicators showing level of oil in tanks, filling pipes, arrangements for freeing tanks from water, suction pipes, return or overflow pipes, steam pipes for filling space in tanks above oil with steam in case of fire, and suitable manholes for cleaning-out purposes. A suitable strainer should be installed on the suction line between the storage tanks and the oil-pressure pumps. The suction line should slope so that it will drain all oil back to the storage tanks when the pump is stopped and a vent opened.

Duplicate oil-pressure pumps should be installed with pump governors, and all piping in connection with these pumps should be cross-connected in such manner that a change can be made from one to the other and repairs made to either without interrupting the service.

A suitable oil heater should be installed, so that the exhaust steam from oil pumps can be utilized to heat the oil before it reaches

the burners. A relief valve should be installed on the discharge line between the pumps and the burners and set at a definite maximum oil pressure.

An oil meter should also be installed in the discharge line to check the storage-tank indicator readings. All oil piping should be installed so that it can be drained back to the storage tanks by gravity in case of necessity.

Provision should be made for removing any condensation from the steam lines to the burners. Automatic regulating devices should be installed to vary the pressure of both oil and steam to the burners in accordance with the demand for steam on the boilers, thus keeping a uniform steam pressure with a variable load, relieving the fireman of constant adjustment of burner valves and enabling him to take care of much larger capacity of boilers than he otherwise could.

In case a plant is operated only ten hours per day, no steam being required for the rest of the twenty-four hours, it is necessary to install a small auxiliary boiler for the purpose of providing steam to atomize the oil while firing up the main boilers.

Methods of Burning Tar.*—Any of the good methods of burning liquid fuel can be used successfully with tar, if it is heated moderately and carefully strained.

The source of supply should be a tank of ample capacity, placed, say, 10 or 12 feet above the burner, and the contents of the tank

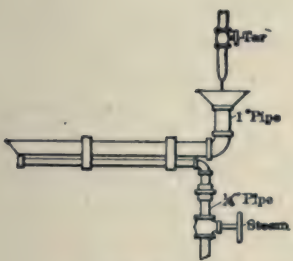

FIG. 53.

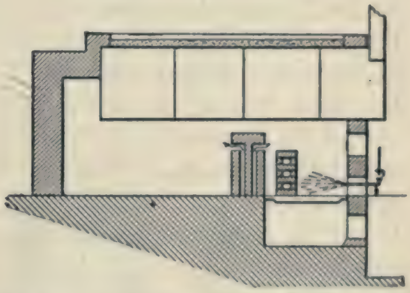

FIG. 54.—COMBUSTION-CHAMBER FOR TAR BURNING.

should be kept warm by low-pressure steam. The tar passing into and leaving the tank should be carefully strained.

Any of the burners used for crude oil will answer for tar. The burner shown in Fig. 53 works well.

* From an article by C. F. Pritchard in *The Engineer* (Chicago), April 1, 1903.

Steam is discharged through a small hole less than 1-16 in. diameter, drilled near the top of the cap on the end of the $\frac{1}{4}$-in. pipe. The overhanging sloping end of the tar pipe in connection with the jet of steam produces a good spray.

In starting a boiler a bed of fuel is necessary, but after a short time the heat of the furnace is sufficient to carry on combustion. It is well to have a large combustion-chamber. The arrangement shown in Fig. 54, where the grates are located at the level of the ash-pit floor, will be found satisfactory. In this arrangement no air is admitted except through a 6-in. square hole around the burner, and a small amount admitted through ports on the bridge wall as shown. This air passes in at ports on the front of the boiler and is heated in ducts in the side walls. This produces a small additional economy, but is not essential to good work.

Deflecting or confining arches or walls erected in the furnace will not last under the intense heat produced by tar burning at its best. A simple loose cob house of fire-brick, as shown, is sufficient. This and the side walls of the furnace become highly heated and ignite the spray of tar, if from any reason it is extinguished.

Furnaces for Burning Green Bagasse and other substances containing a great deal of water, such as wet tan-bark,* require very large fire-brick combustion-chambers, in order to give plenty of room and time for the combustion of the distilled gases before they are allowed to reach the heating surfaces of the boiler. The fuel should be fed either in small quantities at a time or else in a steady stream, so that the evaporation of its moisture may proceed at a uniform rate and chill the furnace as little as possible. Fig. 55 shows an end view of Cook's bagasse burner, placed between two water-tube boilers. It will be observed that the structure is larger than the boiler setting in end view, and its length is also much greater than that of the boiler-setting. It consists of a large fire-brick oven with a smaller chamber beneath. In the rear of the oven, between it and the chimney, a tubular heater is placed, in which the air-supply is heated by the gases on the way from the boiler to the chimney. The fuel is delivered to the furnace automatically, by means of a conveyor.

Fig. 56 shows a bagasse furnace designed by David Moffat Myers. The fuel is fed by gravity to the feed chutes, which are provided with

* For experiments on tan-bark furnaces see page 267.

weighted flaps. The furnace is provided with step grates which give a large area for draft.

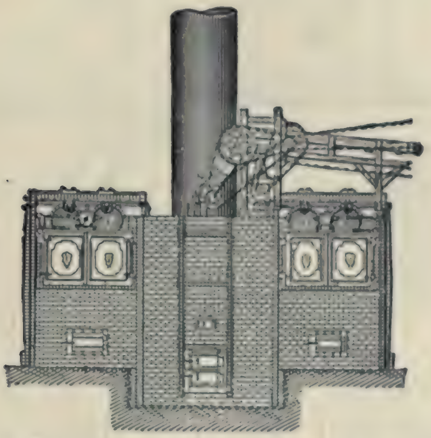

Fig. 55.—Bagasse Furnace, End View.

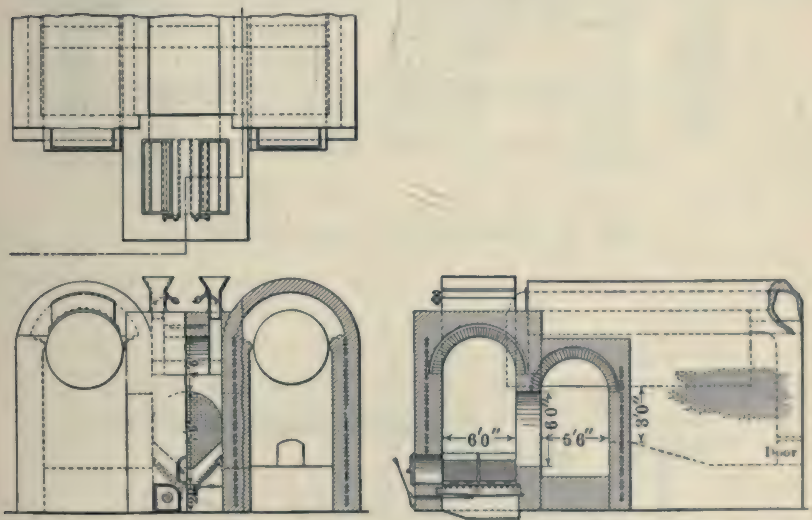

Fig. 56.—Partial Plan, Side and End Elevations of the Myers Furnace for Burning Bagasse.

Furnaces for Burning Wood, Sawdust, etc.—Figs. 57, 58, and 59 show three forms of furnace in common use for burning refuse lumber, shavings, and sawdust in saw-mills and wood-working shops. The

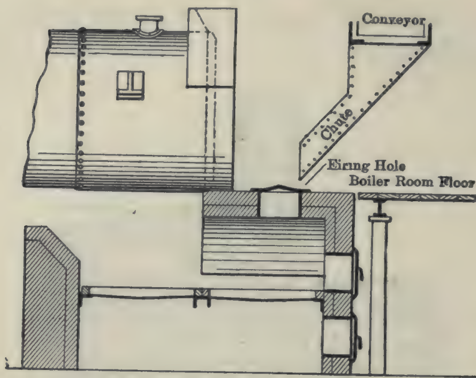

Fig. 57.—Furnace for Sawdust and Shavings.

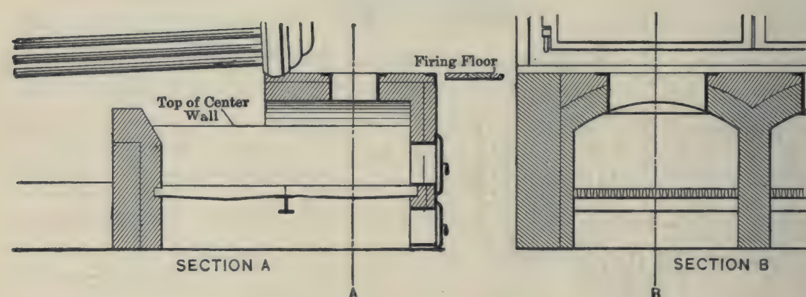

Fig. 58.—Furnace for Lumber Refuse.

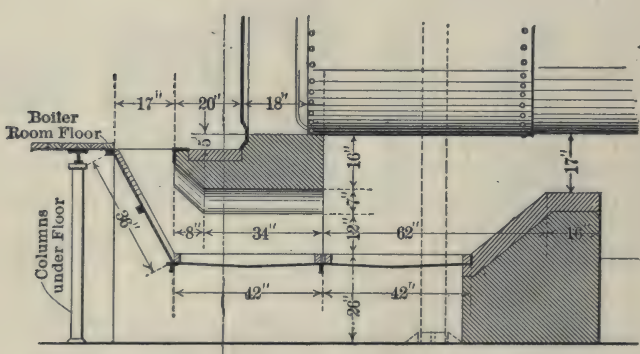

Fig. 59.—Furnace for Refuse Lumber and Sawdust.

first two are known as "Dutch-oven" furnaces. The essential features are: (1) very large combustion-chambers, roofed over with fire-brick; (2) provision for firing the fuel in the front portion of the furnace and pushing the partly burned charcoal to the rear so as to form a deep bed, over which the combustible gases from the freshly fired fuel must pass before they reach the heating surfaces of the boiler. The fuel is generally fed through holes in the roof, the fire-door in front of the furnace being used only for long pieces.

The most common fault of wood-burning furnaces is that they are made too small for the boiler to which they are attached, so that

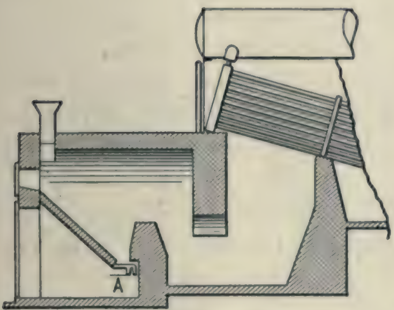

FIG. 60.—STEP-GRATE FURNACE.

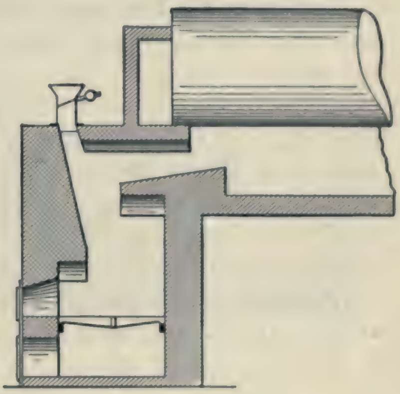

FIG. 61.—BLANDIN FURNACE.

the full capacity of the boiler is not developed. In some cases the trouble may be remedied by lowering the grate bars, thus increasing the size of the combustion-chamber and by blowing air down on and into the burning fuel in addition to supplying it through the grate bars. Shavings and sawdust may be more easily burned by forcing hot air against the pile than by trying to get air through the pile from the grate bars.

The furnace shown in Fig. 59 is said by J. A. Johnston, in *Power*, June 30, 1908, to have proven very satisfactory in burning sawdust with a small mixture of shavings. The grate must be kept covered all the time, or too much air will get through. The fuel is fed in a constant stream from a chute and is shoved back over the grate by a man on the firing floor. Some labor might be saved if the grates were inclined instead of horizontal.

The step-grate furnace, Fig. 60, seems to have too small a grate area and too small volume of combustion space for the large heating surface of the boiler, and the Blandin furnace, Fig. 61, is also deficient in these respects. The hanging wall in Fig. 60 and the projecting arch in Fig. 61 would soon burn out if coal were used in these furnaces.

Sawdust and dry shavings are commonly handled by blowers, the suction of the blower being connected to the saw frame or planer, and the refuse being blown into a receptacle over the boiler room. It is then dropped by chutes directly into the fire, or may be blown directly in by the blast furnishing air for the fire.

Conveyors for Shavings.—The usual method of conveying shavings from wood-working machinery to furnaces or storage bins is the use of a large fan on the suction side of which are pipes branching to the several machines, with a delivery pipe in which the shavings, dust, etc., are blown to the bin or furnace. The Shreveport (La.) Blow Pipe Works has installed many such systems, some of them with Sturtevant exhaust fans 60 in. and 70 in. diameter, with pipes up to 35 in. diameter. At Minden, La., shavings are blown 1500 ft. through a 26-in. pipe.

Furnaces for Burning Wet Tan.—Figs. 62 to 65 show four varieties of furnaces used for burning wet tan bark.* Fig. 62 is a

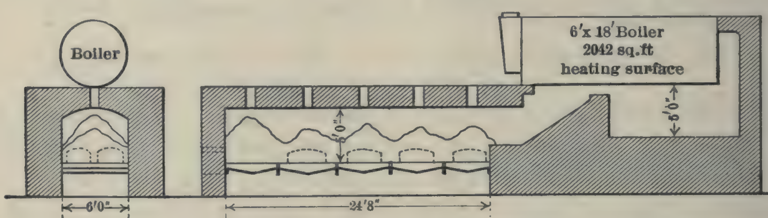

Fig. 62.—The Early Hoyt Furnace for Burning Tan Bark.

very old design, known as the Hoyt furnace. The grate surface is 24 ft. long by 6 ft. wide, and the tan is fed through five holes in the roof and arranges itself into as many piles on the grate. Fig. 63 shows a shorter and wider furnace with six holes. Fig. 64 is a still shorter and wider furnace with four holes designed for the hand firing of a mixture of coal and tan. It is supplied with shaking or shaking

* From a paper by David Moffat Myers on Tan Bark as a Boiler Fuel, Trans. A. S. M. E., 1909.

and dumping grates. Fig. 65 shows what is known as a hump-back grate, which provides increased grate area and at the same time

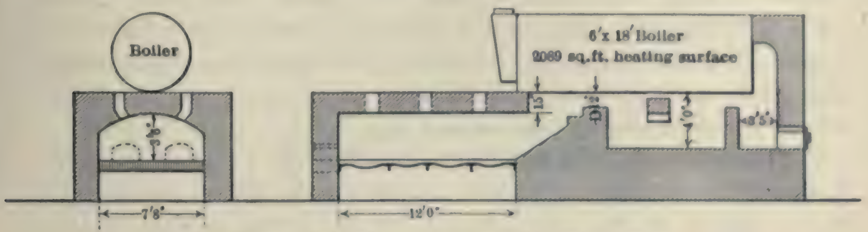

FIG. 63.—A TAN FURNACE WITH SIX FEED HOLES.

The setting had air admission in the bridge wall and a baffle arch in the combustion-chamber. Very good results were obtained.

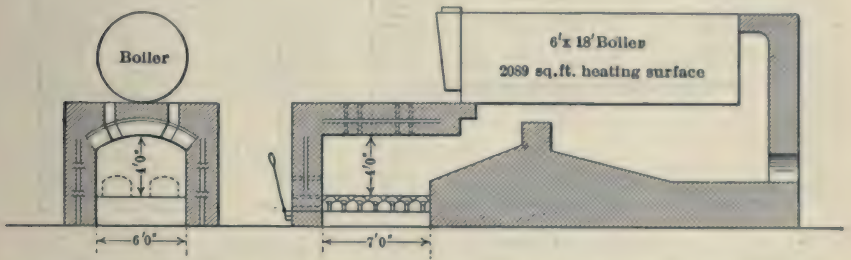

FIG. 64.—A FURNACE WITH SHAKING GRATES FOR BURNING A COAL AND TAN MIXTURE.

Air spaces over fire arch and in walls of furnace and boiler walls. Distance from grate to top of arch inside should not be less than 4 ft.

diminishes the maximum thickness of the pile of fuel on the grate and thus insures a free air supply. The stoke holes in these furnaces are usually provided with circular cast-iron linings. A trouble met with in these types of furnace is the rapid burning away of the fuel next to the side walls, and the consequent large leakage of air from the ash-pit. This trouble is overcome to a great extent by making the furnace about 1 ft. narrower at the grate bars, and for about 1 ft. above them, than the upper part of the furnace.

FIG. 65.—CROSS SECTION OF FURNACE WITH HUMP-BACK GRATES AND BEARING BAR.

The Myers furnace for tan bark or sawdust is similar to the Myers bagasse furnace, Fig. 56, in having step grates and firing chutes above the upper end of each grate. The inside dimensions of one of his furnaces are: length 8 ft., width 5 ft., height from bottom of inclined grates to center of arch, 5 ft. 4 in. Mr. Myers has obtained from a furnace of this type an efficiency as high as 71 per cent based on the available heating value of the fuel.

Furnaces for Burning Sawdust.—Fig. 66 shows a furnace for burning sawdust, used with a 60 H.P. return tubular boiler, and Fig. 67

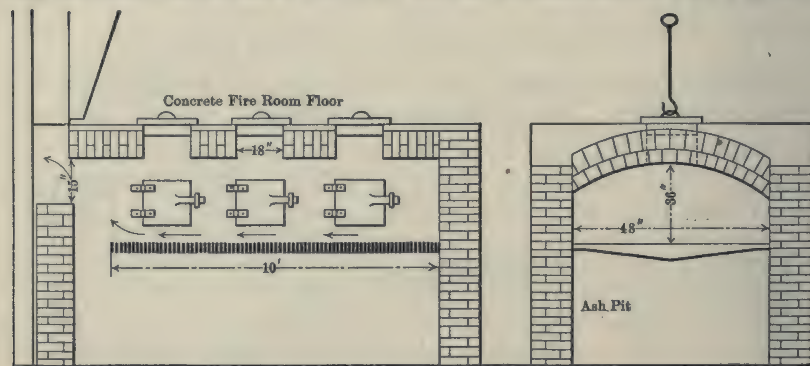

FIG. 66.—FURNACE FOR BURNING SAWDUST.

a furnace for burning either sawdust or oil, or both, used with a 400 H.P. water-tube boiler. In the latter the oil is fed at the rear

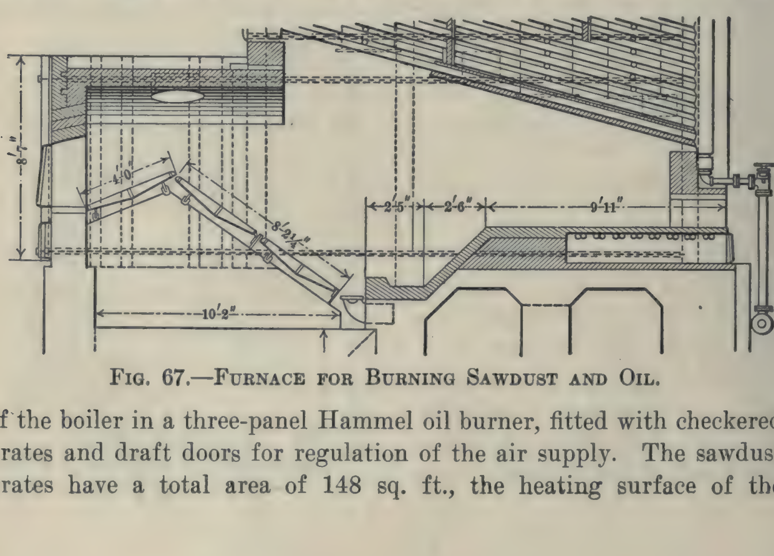

FIG. 67.—FURNACE FOR BURNING SAWDUST AND OIL.

of the boiler in a three-panel Hammel oil burner, fitted with checkered grates and draft doors for regulation of the air supply. The sawdust grates have a total area of 148 sq. ft., the heating surface of the

boiler being 4070 sq. ft., a ratio of 1 to 27.5. The sawdust fuel is fed automatically by two conveyors which bring it from a storage bin.

Volume of Combustion Space Required to Effect Complete Combustion.—Technical Paper 63 of the U. S. Bureau of Mines describes a series of experiments to determine the relation of the completeness of burning the combustible constituents of furnace gas to the volume of the chamber in which they are burned. A Murphy furnace with a projected horizontal grate area of 25 sq. ft. was built at the end of a fire-brick tunnel 3 ft. wide, 2 ft. 8 in. high and 36 ft. long. Samples of gas were taken at the bridge-wall and at seven other points throughout the length of the tunnel. The fuel was Pocahontas semi-bituminous, and the thickness of the bed was about 6 inches. The principal results of the tests are shown in the two tables below. They show that complete combustion (absence of combustible in the gas) was never obtained until the gases had traveled beyond a point in the tunnel corresponding to a total volume of 3.2 cu. ft. per

RELATION BETWEEN COMBUSTIBLE IN FURNACE GAS AND VOLUME OF COMBUSTION SPACE, WITH AIR SUPPLY VARYING

Lbs. Coal per Sq.ft. Grate per Hr.	Average Gas Analysis.		Volume of Combustion Space per Sq.ft. of Grate, Cu.ft.					
	CO_2.	O.	1.9	3.2	4.5	6	9	12
			Combustible in Furnace Gas, per cent.					
20.9	8.1	11.7	0.8	0.3	0.0			
	14.1	5.3	1.6	0.4	0.1			
	17.2	1.9	4.5	1.1	0.1			
28.4	7.4	12.2	0.4	0.2	0.0			
	13.4	5.4	3.3	0.4	0.0			
	16.3	2.9	8.4	1.0	0.2			
37.2	12.6	6.4	1.6	1.2	0.6			
	13.9	5.1	7.6	2.6	0.0			
	16.6	2.4	2.6	0.8	0.0			
44.3	10.4	9.0	1.8	0.2	0.0			
	13.0	6.2	3.1	0.2	0.0			
	16.7	0.3	9.6	5.5	4.0	3.2	2.5	2.4
58.4	10.4	9.4	2.2	0.2	0.0			
	15.9	2.8	6.8	2.4	1.0	0.3	0.2	0.2
	17.2	1.4	7.5	3.4	1.8	1.0	0.6	0.4

RELATION BETWEEN COMBUSTIBLE IN FURNACE GAS AND VOLUME OF COMBUSTION SPACE, FOR AIR SUPPLY CONSTANT AT 25 PER CENT EXCESS

Lbs. Coal per Sq.ft. Grate per Hr.	Volume of Combustion Space per Sq.ft. of Grate, cu.ft.				
	2	3	4	5	6
	Combustible in Furnace Gas, per cent.				
20.9	1.2	0.0			
28.4	3.8	0.4	0.0		
44.3	3.2	0.4	0.0		
58.4	5.0	1.7	0.8	0.4	0.0

sq. ft. of grate area; that the volume of combustion space required increases with increase of the rate of driving and with decrease of the air supply. Many large variations from the average figures were obtained on account of the inadequate control of the air supply and the difficulty of obtaining correct average samples of the gas. The figures should be taken as applicable only to the conditions of these particular tests. The general tendency of the results is what should be expected, since with imperfect mixing of the gas and air in the furnace a longer travel in the tunnel would be required to effect a thorough mixture and complete combustion the smaller the percentage of free oxygen in the gases and the greater quantity of coal burned in a given time. In other words, deficient air supply and rapid driving, with imperfect mixture of gas and air, are chief causes of the making of smoke.

CHAPTER VIII.

SOME ELEMENTARY PRINCIPLES OF STEAM-BOILER ECONOMY AND CAPACITY—THE PLAIN CYLINDER BOILER.

In this chapter we will discuss by a somewhat elementary method, without the use of any algebraic formula, the principles upon which depend the economy and the capacity of the heating surface of a steam-boiler, using for illustration the plain cylinder boiler. In the succeeding chapter the same subject will be treated in another manner, with the use of some mathematics. The conditions which determine to a great extent how large a boiler, or battery of boilers, should be used for a given purpose are: The quantity of steam required; the quality and the cost of fuel; the degree of fuel economy desired; the quality of the water supplied; the regularity of the demand for steam; the size and shape of the space available, etc.

Let us consider how the size and form of a boiler are governed by the conditions of quantity of steam required and by the degree of fuel economy desired.

Instead of taking the problem that is usually presented, viz.: "A certain quantity of steam is required, what shall be the form and size of the boiler to furnish it?" it will better serve the purpose of elementary instruction to state the problem in the reverse manner, viz.: "Given the form and size of a certain boiler, how much steam will it furnish?"

Capacity of a Plain Cylinder Boiler.—We will begin the study of this problem by taking an example of the simplest form of boiler, a plain cylinder of a size that is still commonly used at anthracite coal-mines, viz.: 30 in. diameter and 30 ft. long. It is provided with a setting of brick-work, the side walls being 3 feet apart, and with an ordinary grate, 3 ft. wide and 4 ft. long, or 12 sq. ft. of grate-surface. At the rear end there is a flue leading to a tall chimney. The side walls of the setting are built in at the top so as to touch the boiler at the middle of its height, so that only one-half of the boiler is exposed to radiation from the fire and to contact with the heated gases. The water-level is carried a few inches above the middle of the boiler, so

that at no time is any part of the external surface of the boiler exposed to the flame or heated gases without having water on the opposite inner surface. The boiler is made of steel, $\frac{1}{4}$ inch thick, which is ample for strength, and is supposed to be kept free from scale on the inside and from deposits of soot and ashes on the outside. The upper half of the boiler, above the brick walls, is covered with a non-conducting covering, to prevent excessive loss of heat by radiation. Such a boiler is shown in Fig. 68.

The boiler being 30 ft. long and $2\frac{1}{2}$ ft. external diameter, and the lower half of its surface being heating surface, the area of the heating surface is $\frac{1}{2}$ of $30 \times 2\frac{1}{2} \times 3.1416 = 117.81$ sq. ft. We can make this 120 ft. by letting the side walls touch the heating surface $\frac{1}{2}$ in. above the middle of the boiler; or, if we let them extend $7\frac{1}{2}$ in. above the middle, raising the water-level to correspond, until it is within 5 or 6

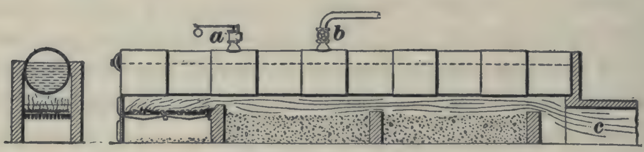

FIG. 68.—PLAIN CYLINDER BOILER.

in. of the top of the boiler, we can make the heating surface equal to two-thirds of the whole external cylindrical surface of the boiler, or 157 sq. ft. This will, however, not be generally advisable, since by bringing the water-level so close to the top of the boiler there would be danger of carrying water into the steam-pipe, making what is known as "wet steam." For the purpose of this calculation, therefore, we will consider the heating surface as 120 sq. ft. The grate-surface being, as already stated, 12 sq. ft., the ratio of heating to grate-surface, which ratio is a term commonly used in describing steam-boiler proportions, is 10 to 1.

This simple form of boiler, when properly built and erected, supplied with good water, and well taken care of, has many excellent qualities, which have caused it to remain a favorite form of boiler in some parts of the world, and especially in the anthracite coal regions of Pennsylvania, ever since high-pressure steam began to be used in steam-engines, a century ago. Its disadvantages, which have caused it to be generally displaced by other forms, will be treated of later. The study of the chief conditions which govern boiler-capacity and boiler-

economy can be more easily begun by reference to this form of boiler than to any other, and it is for this reason that it has been selected for discussion in this place. The theoretical principles which may be developed in treating of this boiler will apply in great measure to all other forms of boilers.

Having thus described the boiler, we are now ready to take up the question, "How much steam will it furnish?" A direct answer to the question is: "That depends on circumstances, and especially upon the amount and upon the quality of coal that is burned under it. One boiler of the form and dimensions here given may furnish three or four times as much steam as another boiler exactly like it." This answer is correct, but it is not sufficiently definite for our purpose. If the capacity of the boiler depends upon circumstances, we wish to know, with some approach to accuracy, what the boiler will do under different sets of stated conditions, and how the conditions affect the capacity of the boiler and at the same time the economy of fuel.

We will begin this study by assuming that under all the different conditions now to be considered the steam-pressure is maintained at 110 lbs., not by means of a damper regulator, which is occasionally used, but by the discharge of the steam into a steam-main fed also by other boilers in which main the steam-pressure is maintained constant under a possible varying demand by means of varying the rate of driving of the other boilers than the one being considered. The uniformity of pressure might also be obtained by having the steam escape through a loaded valve, similar to a safety-valve, which is set so as to open whenever the pressure is 110 lbs., and shut below that pressure. We will also assume that the feed-water is supplied at a temperature of 155° Fahrenheit. These two assumptions are made merely for the purpose of simplifying the problem, and thereby shortening to some extent the arithmetical computations involved. To evaporate a pound of water supplied at 155° F. into steam at 110 lbs., gauge-pressure, requires just 10 per cent more heat than to evaporate a pound of water supplied at 212° F., into steam at ordinary atmospheric pressure at the sea-level, or "from and at 212°," a term frequently used in discussions of boiler-economy. Results of boiler-tests are commonly reduced from the figures obtained under the "actual conditions" of the test to the equivalent evaporation "from and at 212°" by multiplying these figures by a "factor of evaporation," which factor may be found by calculation from the formula $F = (H - h) \div 970.4$, in which H and h are respectively the heat-units in

1 lb. of steam of the given pressure and in 1 lb. of water of the given temperature found in the tables of the properties of steam and water, or it may be taken directly from a table of such factors. In the present case the "actual conditions" assumed are: Feed-water 155°; steam-pressure 110 lbs. by gauge (corresponding to a temperature of 344° F.), and factor of evaporation 1.10.

Calculations of Fuel Economy.—We now assume, as the first condition which governs the rate of driving of the boiler, that the coal used is of a fairly good quality, equal in heating value to an ideal perfectly dry coal containing 85 per cent of pure carbon and 15 per cent ash.

Let us also assume that we have the draft of the boiler, and the thickness of the bed of coal on the grate, so regulated that enough air is supplied to burn the carbon of the fuel thoroughly, forming carbonic acid gas, or CO_2. Each pound of coal burned will require about 20 lbs. of air to burn it, including enough excess of air to insure that no portion of the carbon is burned imperfectly, or to carbonic oxide gas (CO). The 20 lbs. of air supplied per pound of coal will measure about 260 cubic feet, if measured at a temperature of 60° F.

The complete combustion of a pound of coal will generate a definite quantity of heat, which may be calculated and expressed in "heat-units," or "British thermal units."

The quantity of heat which may be produced by the complete combustion of 1 lb. of carbon is, approximately, 14,600 B.T.U.

The quantity of heat required to evaporate 1 lb. of water from a temperature of 212° into steam at the same temperature, or from and at 212°, is 970.4 B.T.U.

The quantity of heat required to evaporate 1 lb. of water supplied at 155° into steam at 110 lbs. gauge-pressure, is 10 per cent greater than this, or 1067 B.T.U.

Dividing 14,600 by 970.4 we obtain 15.05 lbs., which is the quantity of water which may be evaporated and at 212° by the complete combustion of 1 lb. of carbon, on the supposition that all the heat generated is used to evaporate the water and none is allowed to escape by radiation or in the gases produced by the combustion, conditions which are ideal, and impossible to realize in practice.

A coal whose heating value per pound is equal to 85 per cent of that of pure carbon, is theoretically capable of producing 85 per cent of this result, or $0.85 \times 15.05 = 12.79$ lbs. evaporation, from and at 212°, per pound of coal.

If the steam is generated at 110 lbs. pressure from feed-water at 155°, the theoretically possible evaporation is $\frac{100}{110}$ of this, or 12.79 ÷ 1.1 = 11.63 lbs. of steam per pound of coal, 1.1 being the "factor of evaporation."

This is the maximum amount of steam which it is possible, theoretically, to produce from 1 lb. of coal of the quality assumed, and under the conditions given, viz., feed-water at 155° and steam-pressure 110 lbs., in an ideal boiler, in which there is no waste of heat by radiation, by escape in the chimney gases, and no waste of coal by imperfect combustion, by falling through the grate-bars or by removal in the ashes. In practice all these wastes occur, and the percentage of the ideal result which may be obtained in a test ranges from 80, under unusually favorable conditions, down to 50 or even less, when the conditions are unfavorable. If we take 75 per cent as the highest figure which is likely to be reached in every-day practice, with good coal and with a boiler which is well designed and driven at a moderate rate, then we may expect that the coal of the quality given, with feed-water at 155° and steam at 110 lbs., will evaporate 11.63 × .75 = 8.72 lbs. as a maximum; and if the boiler is not properly designed for the service, or is driven at too high a rate, or the air-supply is excessive, the evaporation per pound of coal may be much less than this figure.

Reversing the order of the calculations we have:

Actual evaporation per lb. of coal....................	8.72 lbs.
Equivalent evaporation from and at 212°, 8.72×1.1....	9.59 "
Equivalent evaporation per lb. combustible, 9.59÷85...	11.28 "
Efficiency, 11.28÷15.05..........................	75%

Boiler Capacity Depends Upon Economy.—The discussion thus far has apparently made a wide digression from the problem with which it started, viz.: how much steam will be furnished by the boiler of the form and size selected. The complete answer to the problem, however, is so complicated with the answer to the other question of how much steam may be generated from a pound of coal, that it seemed advisable to first give some consideration to the latter question. It will be seen that the amount of steam that may be made by a boiler of a given size depends upon the amount of coal which may be burned under it, but is not directly proportional to the amount of coal; and the amount of steam that may be generated by the combustion of a pound of coal depends upon the boiler and upon the rate at which the boiler is driven.

Returning now to our cylindrical boiler 30 ft. long, let us suppose that its length is divided into 10 parts or sections, of which the first two sections are directly exposed to radiation from the fire, and the other eight receive heat by conduction from the heated gases in their passage to the chimney. It is evident that the first and second sections will each transmit a greater quantity of heat into the water than the third, that the third will transmit more than the fourth, and so on. The gases will gradually diminish in temperature as they travel from the furnace to the chimney. The amount of heat transmitted to the water by each square foot of heating surface in a given time will depend upon the difference between the temperature of the heated gases on one side of the plate and that of the water on the other side; the greater this difference of temperature the greater the heat transmitted. Experifents show that it varies about as the square of that difference. Thus the heat transmitted will be four times as much when the difference is 1000° as when it is 500°.

Considering then that our boiler is divided into sections, as in Fig. 69, and that a fire is burning on the grate, concuming a certain quantity of coal per hour, and generating a temperature which in the first two sections averages 2600° F., the reduction in temperature may be considered to take place as follows, the temperature being taken at the end of each section:

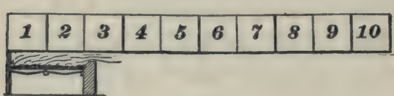

FIG. 69.

Section No.	2	3	4	5	6	7	8	9	10
Temperature F.	2200	1630	1290	1100	970	880	820	770	730
Reduction		570	320	190	130	90	60	50	40

The reduction of the temperature of the consecutive sections is a measure of the quantity of heat transmitted by each section, for the quantity of heated gas remains the same, and the quantity of heat in a given quantity of gas is very nearly proportional to its temperature.

Suppose now we increase the quantity of coal burned on the grate, so that a greater quantity of heated gas is formed. The thickness of the bed of coal being increased with the increase of draft, so that the same amount of air is used per pound of coal, the same temperature in the furnace, viz., 2600°, may be obtained; but the temperatures of the sections beyond the furnace will be higher than before, because the quantity of heated gas and its velocity of passage toward the chimney are both increased, and the capacity of a square foot of heating sur-

face to absorb heat is not increased by the increase in quantity of the gas that passes under it, although it may be increased by the increase of the difference between the temperature of the gas and that of the water in the boiler. The reduction in temperature of the gas in the consecutive sections may now be as follows:

Section No........	2	3	4	5	6	7	8	9	10
Temperature F....	2300	1920	1670	1490	1360	1250	1160	1090	1030
Reduction.........		380	250	180	130	110	90	70	60

Comparing these two statements of the temperature in the different sections, we note several things:

1. In the first case the temperature of 2600° at the furnace is reduced to 730° at the chimney, and in the second case the same temperature at the furnace is reduced only to 1030° at the chimney. In the first case the temperature at the chimney indicates a loss of heat in the chimney gases of $730 \div 2600 = 28$ per cent of the heat in the furnace. In the second case the temperature of 1030° indicates the loss of $1030 \div 2600 = 39.6$ per cent.

2. In the second case the reduction of the temperature in the first three sections is less than that of the corresponding sections in the first case. This does not mean that the heat transmitted is less in the second case than in the first, for the quantity of gas has been increased and there is a greater quantity of heat transmitted while the reduction in temperature is less.

3. In each section in the second case the temperature is greater than in the corresponding section in the first case. The difference between the temperature of the gas and the water is greater, consequently the transmission of heat is greater, and the quantity of steam made by the boiler is greater. The capacity of the boiler therefore depends to a considerable extent on the economy. Increasing the quantity of coal burned increases the capacity while it reduces the economy.

4. Although in the second case a greater quantity of steam is made than in the first, it is not made with the same economy of fuel, for the temperature of the chimney gases is greater, showing that a greater percentage of the heat generated in the furnace has been wasted.

5. Since the reduction of temperature in any section is less than that in the preceeding section, it is evident that in the first case an addition of a few sections to the length cannot add much to the

economy of fuel. In the second case, however, the temperature of the chimney gases being 1030°, it is evident that an addition of several sections to the length might be made before the gases would be reduced to 730°, the temperature of the chimney gases in the first case. It is also evident that increasing the heating surface increases both the capacity and the economy.

Loss of Economy Due to Insufficient Heating Surface.—What has been said above shows the necessity of proportioning the heating surface to the amount of coal to be burned, rather than to the extent of grate-surface; and so proportioning it as to give such an extent of heating surface as will reduce the temperature of the chimney gases to say within 100° or 200° of the temperature of the steam, if economy of fuel is desired.

Some readers may think that all this is so very simple that there should be no need of explaining it at so great length. It all amounts to the simple statement that economy of fuel requires that the temperature of the escaping gases should be low, and that, to secure this low temperature, plenty of heating surface should be given. This is quite true, but it is not at all appreciated by many boiler users. Many of them never think of putting a pyrometer or a thermometer in the stacks of their boilers, to discover by that means whether or not there is a waste of fuel. They are quite satisfied if their boilers give all the steam that is required, and pay little attention to the cost of producing that steam. It has therefore seemed desirable that this chapter should contain not only the simple statement above given, but also in considerable detail the reasoning upon which the statement is founded. A mathematical treatment of the subject will be found in the chapter on "Efficiency of Heating Surface."

To come now to a more definite statement of how great is the loss due to insufficient heating surface, we must have recourse to the records of experiments upon boilers.

In a paper on "Efficiency of Boiler Heating Surface," by Mr. R. S. Hale, Trans. Am. Soc. M. E., vol. xviii., he gave a diagram showing the relation of the evaporation from and at 212° per pound of combustible to the evaporation from and at 212° per square foot of heating surface per hour, as obtained by plotting the results of tests with anthracite coal given in Mr. Geo. H. Barrus's book on "Boiler Tests." This diagram is here reproduced, Fig. 70. The small circles represent the results of each individual test, the lower curve represents what Mr. Hale considers to be the law of the average relation between

the efficiency and the rate of evaporation, and the upper line, passing through five of the small circles, is a line which is added to represent the law of the relation as derived from maximum results. It will be

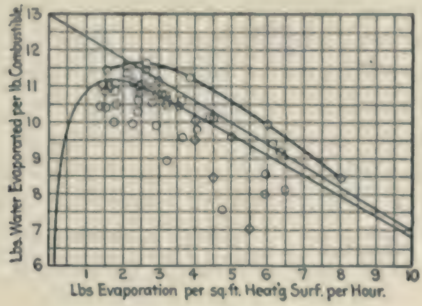

Fig. 70.

noticed how very far below the maximum are some of the individual results.

Maximum Possible Economy.—On another diagram, Fig. 71, is plotted together with this curve of Mr. Barrus's maximum results

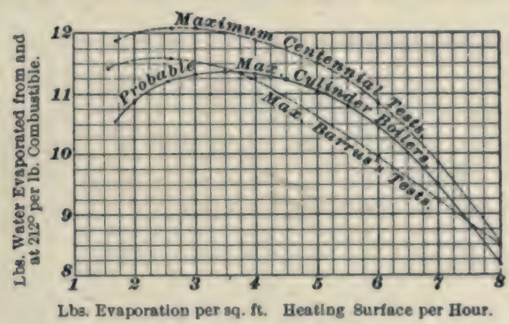

Fig. 71.—Relation of Economy to Rate of Driving.

another curve representing the maximum results obtained in the boiler tests made at the Centennial exhibition in 1876. The particular results through which the curve is drawn are the following:

Name of Boiler.	Lbs. Water Evaporated from and at 212° per sq.ft. H.S. per Hour.	Lbs. Water Evaporated from and at 212° per lb. Combustible.
Firmenich	1.932	11.938
Root	2.586	12.094
Smith	3.739	11.985
Galloway	5.413	11.216
Pierce	6.698	9.865

The smooth curve passes directly through the first four of the above results and a little above the fifth, joining the curve of Mr. Barrus's results at its right-hand extremity.

As the Centennial tests were made under exceptionally favorable conditions, and as the maximum results of these tests have never been surpassed in other competitive tests with anthracite coal in which every precaution was taken by impartial observers to secure accuracy, it is fair to consider this curve as representing the highest possible evaporation in any form of boiler (except when mechanical stokers are used) for the several rates of evaporation per square foot of heating surface here given. Taking approximate values along different portions of the curve we have the following:

POUNDS OF WATER EVAPORATED FROM AND AT 212°.

Per. sq. ft. of heating surface per hour.....	1.7	2	2.5	3	3.5	4	4.5	5	6	7	8
Per lb. of combustible..	11.9	12	12.1	12.1	12	11.85	11.7	11.5	10.8	9.8	8.5
Efficiency, estimated, %.	77.7	78.3	79	79	78.3	77.3	76.4	75.1	70.5	65	55

Assuming anthracite to have a heating value of 14,800 B.T.U. per lb. combustible.

The Centennial tests were all made upon other forms of boiler than the plain cylinder, and the same is true of Mr. Barrus's tests. There is no record published of any comprehensive series of tests upon plain cylinder boilers from which we might draw a curve expressing the relation of the efficiency to the rate of evaporation, but we may make certain reasonable assumptions concerning them which may enable us to draw a probable curve.

The first assumption is that the form of the plain cylindrical boiler is exceedingly favorable to the absorption of the greatest possible quantity of heat by every square foot of its heating surface. The flames and heated gases travel steadily along this surface, the tendency of heated gases always to ascend tending continually to keep the hottest portion of the gas in contact with the surface above it. There is no shorter path by which the gases may reach the chimney; hence, there is no tendency to short-circuiting the gases, which is a serious defect in many other forms of boiler. The thickness of the metal in the shell, rarely more than ½ inch, is not so great as to cause an appreciably greater resistance to the passage of heat through it than that through the thin tubes of tubular boilers. The form of the plain cylinder boiler seems, therefore, to be as well adapted to the absorption of heat as that of any other boiler, and there seems to be every

reason to believe that, as far as the absorption of heat through its shell from the heated gases is concerned, it should be quite as efficient as the best of the boilers tested at the Centennial exhibition, and that the curve expressing its maximum results would follow closely the curve of maximum results of the Centennial tests, unless there is some other cause not yet considered which would prevent it.

Loss of Heat by Radiation.—There is such a cause, and that brings us to the second assumption, viz., that the radiation loss of the plain cylinder boiler is very much greater than that of the modern types of boiler which were tested at the Centennial exhibition. The cylinder boiler, 30 ft. long and 30 in. diameter and having 120 sq. ft. of heating surface, will have approximately 120 sq. ft. in the upper half of its shell covered with a non-conducting covering, more or less imperfect, and the two brick side walls would be about 240 sq. ft. These two

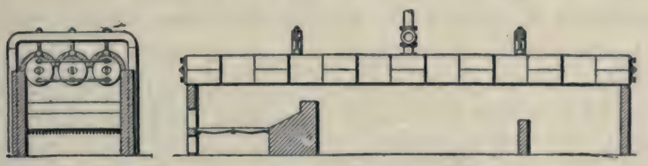

FIG. 72.—BATTERY OF PLAIN CYLINDER BOILERS.

side walls, however, might be used for a battery of three or four boilers, as in Fig. 72. A return tubular boiler of double the diameter and half the length of the cylinder boiler, or 5 × 15 ft., would have only about 80 sq. ft. of the upper portion of its shell covered with a non-conductor, and about 240 sq. ft. side walls, which might also be used for a battery of boilers. But the tubular boiler might have, say, 60 4-in. tubes inside of it, with a total heating surface of about 940 sq. ft., which are entirely surrounded by water, and therefore contribute nothing to the loss by external radiation. The total heating surface of the tubular boiler would be about 1100 sq. ft., or nine times as great as that of the cylinder boiler, and yet would expose less surface to external radiation, so that the loss of heat by radiation from the cylinder boiler must be much greater than from the tubular boiler. How much greater we have no means of knowing, in the absence of direct experiments. Mr. Hale, in the paper before mentioned, in discussing tests with other boilers than plain cylindrical, says that the radiation in some of these tests could not have been over 2 per cent when the boilers were driven at a rate of evaporation of 3 lbs. of water per sq. ft. of heating surface per hour, and that "it does not seem possible that the radiation

could in modern practice have gone up to much over 6 or 7 per cent at most, and it is probable that it is not over 5 per cent if it is as much as that." The "modern practice" referred to by Mr. Hale, is not practice with plain cylinder boilers, which latter may be called ancient practice, since plain cylinder boilers are now used in only a few localities. We will probably not be far from correct if we assume that the radiation from plain cylinder boilers is 5 per cent greater than from the boilers tested at the Centennial exhibition, when the calculation of the radiation is made on the basis of the rate of evaporation being 3 lbs. per sq. ft. of heating surface per hour, this 5 per cent being that percentage of the total heating value of the pound of combustible. This heating value, 14,600 B.T.U., being equal to an evaporation of 15.05 lbs. of water, 5 per cent of this is 0.75 lb., which we may assume to be the extra loss by radiation in a plain cylinder boiler over that in a modern type of boiler when the rate of evaporation is 3 lbs. per sq. ft. of heating surface per hour. When the rate of evaporation is doubled the percentage will be halved, and the extra loss by radiation will then be 0.38 lb. If the rate of evaporation is less than 3 lbs. the percentage loss will be greater. Subtracting the extra loss as calculated from the figures already given as taken from the curve of maximum results of the Centennial tests, we have the following:

MAXIMUM ECONOMY OF PLAIN CYLINDER BOILERS: POUNDS WATER EVAPORATED FROM AND AT 212°.

Per square foot heating surface per hour............	1.7	3	3.5	4	5	6	8
Per lb. combustible, max. of other boilers, Centennial tests....................	11.90	12.05	12.00	11.85	11.50	10.85	8.50
Subtract extra radiation loss for cylinder boilers.......	1.32	.75	.64	.56	.45	.38	.28
Probable max. per lb. combustible, cylinder boilers...	10.58	11.30	11.36	11.29	11.05	10.47	8.22

The figures in the last line have been plotted in the diagram, Fig. 71, and a curve drawn through them. It will be seen that the maximum economy is at a rate of evaporation of 3.5 lbs. per square foot of heating surface, that below this rate the economy is decreased on account of the loss by radiation, and that above this rate the economy falls, at first slowly, and later very rapidly, until at a rate of evaporation of 8 lbs. per square foot of heating surface per hour the evapora-

tion is only 8.22 lbs. per lb. of combustible, as compared with the maximum of 11.35 lbs. at a rate of 3.5 lbs.

Beyond the rate of 8 lbs. per square foot, the direction of the curve between 7 and 8 lbs. being continued in a straight line, as the shape of the curve seems to indicate, there would be a decrease in the evaporation per lb. of combustible of about 1.3 lbs. for every increase of 1 lb. in the rate, and the curve would cut the line representing 0 lbs. evaporation per pound combustible at a rate of a little over 14 lbs.

Capacity of a Plain Cylinder Boiler at Different Rates of Driving.—We now have the data from which to calculate the probable amount of steam that will be made by the plain cylinder boiler, of the size selected, at different rates of driving.

PROBABLE MAXIMUM WORK OF A PLAIN CYLINDRICAL BOILER OF 120 SQ. FT. HEATING SURFACE AND 12 SQ. FT. GRATE SURFACE AT DIFFERENT RATES OF DRIVING.

Rate of driving; lbs. water evaporated per sq. ft. of heating surface per hour..	1.7	3	3.5	4	5	6	8
Total water evaporated by 120 sq. ft. heating surface, per hour, lbs.........	204	360	420	480	600	720	960
Horse-power; 34.5 lbs. per hour = 1 H.P.	5.83	10.43	12.17	13.91	17.39	20.87	27.83
Pounds water evaporated per pound combustible.........................	10.58	11.30	11.36	11.29	11.05	10.47	8.22
Pounds combustible burned per hour....	19.3	31.9	37.0	42.6	54.3	68.8	116.8
Pounds combustible per hour per sq. ft. of grate.........................	1.61	2.66	3.08	3.55	4.52	5.73	9.73
Pounds combustible per hour per horse-power.........................	3.31	3.06	3.04	3.06	3.12	3.30	4.16

From the figures in the last line we see that the amount of fuel required for a given horse-power is nearly 37 per cent greater when the rate of evaporation is 8 lbs. than when it is 3.5 lbs.

The figures in the above table which represents the economy of fuel, viz., "Pounds water evaporated per pound combustible," and "Pounds combustible per hour per horse-power," are what may be called "maximum" results, and they are the highest that are likely to be obtained with anthracite coal with the most skillful firing and with every other condition most favorable. Unfavorable conditions, such as poor firing, scale on the inside of the heating surface, dust or soot on the outside, imperfect protection of the top of the boiler from radiation, leaks of air through the brickwork, or leaks of water through the blow-off pipe, may greatly reduce these figures.

Disadvantages of the Plain Cylinder Boiler.—An inspection of the figures will reveal one of the reasons why in most parts of the world the plain cylinder boiler is no longer used. The boiler we have selected for illustration is of quite large size, 30 feet long, 2½ feet wide, occupies a considerable area of ground, and requires quite a costly setting; yet when driven at its most economical rate, it develops only 12.17 H.P., or when driven at such a rate that its fuel consumption per H.P. is 37 per cent greater than at its most economical rate, it develops only 27.83 H.P. It can be made to develop a still greater horse-power, but only by a much greater waste of fuel. Where fuel has no marketable value, such as sawdust and waste lumber at saw-mills, refuse coal at coal-mines, and the like, the question of fuel economy is of no importance; but even in such cases, in which, say, 10 or more pounds of water may be evaporated per square foot of heating surface per hour, equal to 35 H.P. developed by a boiler of 120 sq. ft. heating surface, it is probable that the first cost of the plain cylinder boiler, including setting, is greater than that of some more modern form of boiler. Where refuse coal is used as fuel, the cost of hauling it and the cost of removal of ashes should be considered, and it may be found that these costs alone, even when fuel costs nothing, justify the use of a boiler which economizes fuel.

Suppose a plant of boilers at a coal-mine is used to generate 1000 H.P. of steam. Refuse coal is used, and the boilers are driven at such a rate that 4 tons of coal are used for every 3 tons that would be used by boilers driven at an economical rate. It requires four men to handle the coal and ashes, while only three men would be required with the economical boiler-plant. The saving of one man's wages, say, $450 per year, is equal to 5 per cent on an investment of $9000, or 10 per cent on an investment of $4500. So, if the economical boiler-plant of 1000 H.P. did not cost over $4000 above that of an uneconomical boiler-plant, its purchase would be justified from a financial standpoint even in a case where fuel costs nothing.

Besides the objections to the plain cylinder boiler already spoken of, viz., great first cost when driven at an economical rate, great waste of fuel when forced much beyond this rate, and excessive ground space occupied, there are others, some of which the plain cylinder boiler holds in common with other styles. The first of these objections, which is common to all very long boilers, is the difficulty of supporting them in such a manner that excessive strains are not created in the sheets and rivets by the weight of the boiler and the water inside

of it, in addition to the strain due to the pressure of steam. When a long boiler is suspended from two points, whether located at the ends or at some distance from them, the stresses due to weight, which tend to rupture the boiler by bending it, may be calculated; but when supported at three or more points the stresses are indeterminate—one support may sustain much more weight than the other—and the strain on some portion of the shell or riveted seams may be greater than a proper regard for safety would admit. These strains are apt to be changed in amount or in direction, as from tension to compression, or *vice versa,* with the changes in temperature in boiler and setting which take place when the boiler is put into or out of service. Even if the maximum strains due to the weight of the boiler may not of themselves be sufficient to endanger the safety of the boiler when new, their continuance during a period of years may make the iron hard and brittle, and hence give rise to danger; or the iron may in time become weakened by corrosion, and then the strains caused by weight of the boiler may become dangerous.

Saving Waste Heat of the Plain Cylinder Boiler.—The chief faults of the plain cylinder boiler, its deficiency of heating surface and high first cost compared to its capacity when driven at anything like an economical rate, have led, as already stated, to its general abandonment wherever the cost of fuel is a matter of importance. In some old plants, however, where cylindrical boilers are already in use, and when they are still in good condition to furnish steam of the pressure desired, but are driven at such a rate as to be wasteful in fuel, it has been found economical, instead of replacing the old boilers with new ones, to add to them an " economizer" in which a large part of the waste heat may be saved.

Use of a Water-tube Boiler as an Addition to a Cylinder Boiler.—Sometimes it is found that the waste gases from a cylinder boiler are so high in temperature that they may be advantageously utilized by passing them into another boiler. Several of the modern forms of water-tube boiler may thus be used. An instance is given below:

At one of the Philadelphia & Reading collieries, one 250 H.P. Cahall vertical boiler was placed at the rear of twelve plain cylinder boilers of the ordinary dimensions common in anthracite colliery practice. A simultaneous test was made, in 1896, by J. M. Whitham, of the performance of the cylinder boilers and the Cahall boiler. Mr. Whitham summarized his results as follows:

1. The cylinder boilers are run to develop from 33 to 35 H.P. each.

2. The cylinder boilers by themselves evaporate 3.77 lbs. of water from and at 212° per lb. of dry coal.

3. The combination of cylinder boilers and Cahall boilers, the latter using waste heat only, permits an evaporation of 6.98 lbs. of water from and at 212° per lb. of dry coal.

4. The waste gases enter the Cahall setting at about 1600° F., and leave it about 700°.

5. The use of waste gases by the Cahall boiler increases the available horse-power of the plant from 74 to 85 per cent, according to the number of boilers used for supplying the waste heat.

6. The 250-H.P. Cahall boiler using waste gases from eight cylinder boilers developed 207.6 boiler H.P., and when supplied by twelve boilers, it developed 334 H.P., or 33.6% above its rating.

7. The fuel used, called a "rice mixture," consisted of 20% slate pickings, 8% buckwheat, 46% rice-coal, and 26% dirt. It contains, as used at this colliery, from 6.25 to 9.5 per cent moisture, and from 32.4 to 34 per cent ash and refuse. It is burned with a strong fan-blast.

CHAPTER IX.

EFFICIENCY OF THE HEATING SURFACE.

ASSUMING that the fuel is burned completely in the furnace, generating a quantity of hot gas, which contains all the heat produced by the combustion, we now have to consider what proportion of this heat is absorbed by being transmitted through the metal heating surface of the boiler into the water; in other words, what is the efficiency of the heating surface. This will depend not only on the nature, extent, and arrangement of the heating surface, that is, on the boiler itself, but also on the rate at which it is driven, and on other conditions of its operation. A theoretical discussion of the subject will first be given, and then the relation of the theory to practice will be shown.

NOTATION.

S = area of heating surface in sq. ft.

W = actual water evaporated, lbs. per hour, reduced to equivalent evaporation from and at 212°, or U.E.* per hour.

W' = the same when radiation is so small that it may be neglected, or W + radiation, in U.E. per hour.

K = heating value of the fuel in B.T.U. per lb.†

K_1 = modified value of K, after making allowances for imperfect combustion and for hydrogen and moisture in the fuel.

F = fuel used, lbs. per hour.

f = weight of dry gases per lb. of fuel.

f_1 = modified value of f, allowance being made for moisture in the gases and for the specific heat of superheated steam.

$w = Ff$, = weight of dry gases, lbs. per hour.

c = specific heat of gas, considered as a constant.

t = excess of the temperature of the water in the boiler above the atmospheric temperature.

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* U.E. = units of evaporation, = 970.4 B.T.U.

† The "fuel" may be taken either as coal or as combustible.

T = temperature (above atmospheric) of the gas in contact with some given portion of the heating surface.

T_1, T_2 = initial and final values of T.

cwT_1 = total heat supplied to the gas by the burning of the fuel, on the supposition that all of the heat generated is first utilized in raising the temperature of the gas before it comes in contact with the heating surface.

cwT_2 = heat lost in the gases escaping to the chimney.

a = a coefficient of resistance to transmission of heat, and of other elements of inefficiency, more fully explained later.

a_1 = the coefficient a modified, allowances being made for incomplete combustion and for hydrogen and moisture in the coal.

E_p = possible evaporation, in U.E. per lb. of fuel if all the heating value of the fuel were utilized.

E_a = actual evaporation, in U.E. per lb. of fuel.

E_a' = same when radiation is not taken into account, or E_a + radiation, in U.E. per lb. of fuel.

R = radiation in U.E. per sq. ft. of heating surface per hour.

In what follows we shall at first consider the radiation so small that it may be neglected.

$$\text{Efficiency of the heating surface} = \frac{E_a'}{E_p} = \frac{cw(T_1 - T_2)}{cwT_1} = \frac{T_1 - T_2}{T_1}. \quad (1)$$

This fraction is the ratio of the heat absorbed by the boiler to the heat supplied by the fuel.*

q = rate of conduction in U.E. per hour per sq. ft. of heating surface, corresponding to any difference of temperature $T - t$ of the gas and of the water.

qdS = heat transmitted per hour through any small portion dS of the heating surface.

$cwdT$ = heat lost by the gas in passing over the portion of heating surface dS; $qdS = cwdT$.

After the hot gas passes over the elementary portion dS of the heating surface, losing the temperature dT, it arrives at the next equal

* Rankine uses a different expression for efficiency, viz., $\frac{T_1 - T_2}{T_1 - t}$, or the ratio of the heat absorbed to the heat which would be absorbed if the gases were cooled down to the temperature of the water in the boiler. This is not as convenient as the expression used above, and it is not in harmony with the usual definition of efficiency, viz., energy utilized ÷ energy supplied.

elementary portion with a diminished temperature, and transmits heat through it at a diminished rate, since the rate of conduction q decreases in some ratio with the decrease of the difference of temperature $T - t$; and so on, transmitting a less and less quantity through each successive equal portion of surface, until it finally leaves the heating surface at the temperature T_2.

For the whole heating surface S, and the corresponding decrease of temperature of the hot gas from T_1 to T_2, we have the integral of the above differential expression:

$$cw(T_1 - T_2) = \int qdS,$$

or

$$\frac{S}{cw} = \int_{T_2}^{T_1} \frac{dT}{q}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The second member of this last equation may be integrated when we find the law of the relation of q to $T - t$.

Rankine represents these principles graphically as follows:

Draw AD, Fig. 73, to represent the whole heating surface S, and let any portion of that line, as AX, represent s, a part of that surface. Let $AB = q_1$, the rate of conduction for the initial temperature T_1. In DA produced, take $AO = \frac{cw(T_1 - t)}{q_1}$; then the rectangle $OABC$ will equal the whole heat of the hot gas proceeding from the furnace per hour, measured above the temperature t; for

$$AO \times AB = AO \times q_1 = cw(T_1 - t).$$

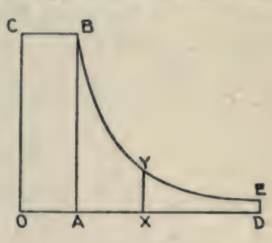

FIG. 73.

Let $XY = q =$ the rate of conduction corresponding to the temperature of the gas after having passed over the portion AX of the heating surface, and let BYE be a curve drawn through the summits of a series of such ordinates; then the area of any part of that curve, such as $ABYX$, represents the heat transferred per hour through the part AX of the heating surface; and the area $ABED$ the heat transferred through the whole surface AD; and when the curve BYE is produced indefinitely, the area contained between it and its asymptote, AD produced, approximates indefinitely to that of the rectangle $OABC$.

The definite results of these principles depend on the relation between q and T_1.

For small differences of temperature it is found experimentally that the rate of transmission of heat through metal plates is nearly proportional to the difference of temperature of the fluids on the two sides of the plate, but for great differences of temperature, such as those existing in steam-boiler furnaces, the transmission increases at a faster rate than the difference of temperature, so that it is nearly proportional to the square of the difference, as is shown by Blechynden's experiments, which will be described later. Rankine gives $q = \dfrac{(T - t)^2}{a}$, in which a is a coefficient whose value may be determined by experiment, and he gives its value as from 160 to 200. The method of deducing the value of a from data of experiments on steam-boilers will be given later; and it will also be shown that it is a function of other things besides the resistance of the metal to the transmission of heat.

Using this value of q we have

$$\frac{S}{cw} = a\int_{T_2}^{T_1} \frac{dT}{(T - t)^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Whence *

$$\frac{S}{cwa} = \frac{1}{T_2 - t} - \frac{1}{T_1 - t} = \frac{T_1 - T_2}{(T_2 - t)(T_1 - t)}. \quad . \quad . \quad (4)$$

By combining equations (1) and (4) we may obtain

$$\frac{E_a'}{E_p} = \frac{(T_1 - t)^2 \div T_1}{(T_1 - t) + \dfrac{acw}{S}} = \frac{(T_1 - t)^2 \div T_1}{(T_1 - t) + \dfrac{acfF'}{S}}, \quad . \quad . \quad . \quad (5)$$

in which equation T_2 has disappeared. (Appendix, note 2.) Let $\dfrac{T_1 - t}{T_1} = B$, and $\dfrac{acf}{T_1 - t} = A$; $acf = (T_1 - t)A$. Then (5) becomes

$$\frac{E_a'}{E_p} = \frac{(T_1 - t)B}{(T_1 - t) + (T_1 - t)\dfrac{AF}{S}} = \frac{B}{1 + \dfrac{AF}{S}}. \quad . \quad . \quad (6)$$

$$BE_p = E_a' + E_a'\frac{AF}{S}, = E_a' + \frac{E_a'AW'}{SE_a'}, \text{ since } F = \frac{W'}{E_a'}.$$

Hence

$$E_a' = BE_p - \frac{AW'}{S}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

* See note 1, appendix to this chapter, page 335.

which is the equation of a straight line if E_a' and $\frac{W'}{S}$ are variables. It shows that the evaporation per pound of fuel is a function of the rate of evaporation per square foot of heating surface, and is affected by two coefficients, A and B.

B, being a function of the initial temperature of the gas T_1, depends on the heating value of the fuel and on the volume of gas, that is, on the air-supply. Let K = heat-units developed in the furnace per lb. of fuel burned, $= T_1fc$. Then

$$B = \frac{T_1 - t}{T_1} = \frac{\frac{K}{fc} - t}{\frac{K}{fc}} = \frac{K - tcf}{K}, \quad . \quad . \quad . \quad . \quad (8)$$

and
$$A = \frac{acf}{T_1 - t} = \frac{ac^2f^2}{K - tcf}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

expressions from which we may find the value of A and B when the heating value of the coal, the temperature of the water in the boiler, the weight of gas per lb. of fuel, and the specific heat of the gas are known. The value of A, however, depends upon that of the experimental coefficient a.* (See Appendix, note 3.)

Values of the Coefficients B and A.

If in the equations $B = \frac{K - tcf}{K}$ and $A = \frac{ac^2f^2}{K - tcf}$ we substitute assumed numerical values as follows: K = 13,000, 14,000, and 15,000; t = 250 and 300; c = 0.24; f = 20, 30, and 40; a = 200, 300, and 400, we obtain values of B and A as follows:

Values of $B = \frac{K - tcf}{K}$.

For t = 250°	250°	250°	300°	300°	300°
f = 20	30	40	20	30	40
For K = 13,000, B = .91	.86	.82	.89	.83	.78
= 14,000, B = .91	.87	.83	.90	.85	.79
= 15,000, B = .92	.88	.84	.90	.86	.81

* Up to this point the treatment of this subject is based partly on that of Rankine ("Steam-engine" p.262) and partly on that of Hale (Trans. A. S. M. E., vol. xviii. p. 330). What follows is original work of the author.

Values of $A = \dfrac{ac^2f^2}{K - tcf}$.

For $t=$	250°	250°	250°	300°	300°	300°
$f=$	20	30	40	20	30	40
For $K=13{,}000$, $a=200$, $A=$	.39	.92	1.74	.40	.95	1.82
$=300$, $A=$	.59	1.39	2.61	.60	1.43	2.73
$=400$, $A=$	.78	1.85	3.48	.80	1.91	3.64
For $K=14{,}000$, $a=200$, $A=$	.36	.85	1.59	.37	.87	1.66
$=300$, $A=$	.54	1.27	2.38	.55	1.31	2.48
$=400$, $A=$	.72	1.70	3.18	.73	1.75	3.31
For $K=15{,}000$, $a=200$, $A=$	.33	.79	1.46	.34	.81	1.52
$=300$, $A=$	.50	1.18	2.19	.51	1.21	2.28
$=400$, $A=$	.67	1.57	2.93	.68	1.61	3.04

Graphical Interpretation of Formula (7).—On a system of rectangular co-ordinates, Fig. 74, lay out E_p and BE_p as ordinates and $\frac{W'}{S}$ as abscissa. From the end of the ordinate BE_p draw a straight line inclining downwards at an angle whose tangent is A. Then for any value of the abscissa $\frac{W'}{S}$ the corresponding value of E_a' will be the length of the ordinate drawn from the extremity of $\frac{W'}{S}$ to the inclined line. The inclined line can never reach the axis of abscissas, and the rate of evaporation $\frac{W'}{S}$ can never be as great as $\frac{BE_p}{A}$. (Appendix, note 4.)

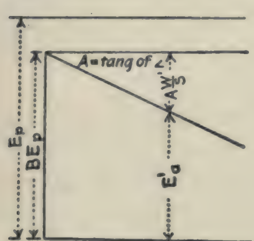

FIG. 74.

Radiation Considered.—In the above formulas no account has been taken of radiation into the atmosphere from the external walls of the boiler and furnace. For a given value of F and S radiation will tend to reduce the values of E_a' and W'. Let r = radiation expressed in units of evaporation per lb. of fuel, then total radiation per hour $= rF$, and radiation in U.E. per hour per sq. ft. of heating surface $= \frac{rF}{S} = R$.

$$E_a' = E_a + r. \quad W' = W + RS.$$

Formula (7) then becomes

$$E_a = BE_p - A\left(\frac{W}{S} + R\right) - r. \quad . \quad . \quad . \qquad (10)$$

For a given temperature t of the water in the boiler and ordinary furnace conditions, rF and R will be practically constant. They will

represent but a small percentage of the heat generated in the furnace when the rate of driving is high, and a large percentage when the rate becomes very low.

If R_0 = radiation expressed as a ratio (or percentage ÷ 100) of the total heat generated (or of the possible evaporation E_p) and R, r, W, S, and E_a are as already defined, $R_0 = \frac{r}{E_p} = R\frac{S}{W}\frac{E_a}{E_p}$; that is, the per cent loss by radiation is proportional to the radiation factor R and to the efficiency E_a/E_p, and inversely proportional to the rate of driving W/S.

Graphical Representation of Formula (10).—Formula (10) may be expressed $E_a = BE_p - A\frac{W}{S} - AR - r$, and it may be represented graphically as in Fig. 75, the height E_a of any point of the curved line above the base line representing the actual evaporation corresponding to a certain rate of evaporation W/S. In the equation there are three quantities which are subtracted from BE_p, and these are shown on the diagram: AR, a constant; AW/S, which increases directly as W/S; and $r = RS/F$, which increases rapidly as W/S approaches 0. When W/S and $E_a = 0$, $r = BE_p - AR$.

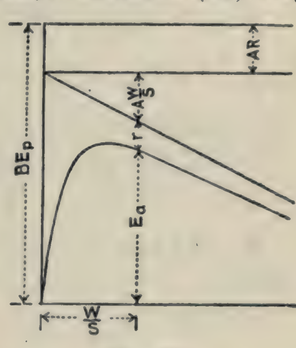

FIG. 75.

Efficiency when Radiation is Considered.—We have

$$r = \frac{RS}{F} = \frac{RSE_a}{W}, \quad \text{since} \quad R = \frac{rF}{S} \quad \text{and} \quad F = \frac{W}{E_a}.$$

Substituting this value of r in eq. (10) it becomes

$$E_a = BE_p - A\left(\frac{W}{S} + R\right) - \frac{RSE_a}{W} = \frac{BE_p}{1 + \frac{RS}{W}} - A\frac{W}{S}. \quad . \quad (11)$$

(See note 5, Appendix.)

$$\text{Efficiency} = \frac{E_a}{E_p} = \frac{B}{1 + \frac{RS}{W}} - \frac{AW}{SE_p}. \quad . \quad . \quad . \quad (12)$$

An Arithmetical Example.—Consider first the case in which radiation is so small that it may be neglected. We will suppose the fol-

lowing data to have been obtained in a test of a boiler, and assume that all the fuel is completely burned, the whole of the heat generated being first applied to raising the temperature of the gases of combustion before they come in contact with the heating surface:

Heating value of the fuel $= K = 13{,}570$ B.T.U. per lb.;
$E_p = 13{,}570 \div 970.4 = 13.98$ U.E. per lb. of fuel,
$S = 1000$ sq. ft.; $F = 300$ lbs. per hr.;
$W = 75\%$ of $13.98 \times F = 10.485 \times 300 = 3145$ lbs. per hour;
$f = 24$ lbs. gas per lb. fuel; $c = 0.24$, specific heat;
$w = Ff = 7200$ lbs. gas per hour.
$T_1 = \frac{K}{fc} = \frac{13{,}570}{5.76} = 2356°$ elevation above atmospheric temperature;
$\frac{T_1 - T_2}{T_1} = 75\%$ efficiency; $T_2 = 25\%$ of $2356 = 589°$;
$t =$ temperature of water $-$ atmospheric temperature,
$= 341°$ F. $- 60° = 281°$;
$T_1 - T_2 = 1767°$; $T_1 - t = 2075°$; $T_2 - t = 308°$.

We now have all the values required for substitution in formula (4) except a.

Formula (4) is

$$\frac{S}{cwa} = \frac{1}{T_2 - t} - \frac{1}{T_1 - t} = \frac{T_1 - T_2}{(T_2 - t)(T_1 - t)}.$$

Substituting the values, we have

$$\frac{1000}{0.24 \times 7200 \times a} = \frac{1}{308} - \frac{1}{2075} = \frac{1767}{308 \times 2075}.$$

Whence $a = 209.3.$

Take now formula (7), $E_a' = BE_p - A\frac{W'}{S}.$

$$B = \frac{T_1 - t}{T_1} = \frac{2075}{2356} = 0.8807;$$

$$A = \frac{acf}{T_1 - t} = \frac{209.3 \times 0.24 \times 24}{2075} = 0.581$$

or, from eq. (8), $B = \frac{K - tcf}{K} = \frac{13{,}570 - 281 \times 0.24 \times 24}{13{,}570} = 0.8807;$

and eq. (9), $$A = \frac{ac^2f^2}{K - tcf} = \frac{209.3 \times 0.24^2 \times 24^2}{13,570 - 1619} = 0.581.$$

$$E_a' = BE_p - A\frac{W'}{S} = 0.8807 \times 13.98 - 0.581\,\frac{3145}{1000} = 10.485.$$

$$\frac{E_a'}{E_p} = \frac{10.485}{13.98} = 75\%\text{ efficiency.}$$

2. We will now assume that radiation from the boiler and furnace amounts to 2% of the heating value of the fuel, reducing the efficiency to 73% instead of 75.

$$2\%\text{ of }E_p = 13.98 \times .02 = 0.280 = r.$$

$$R = \frac{rF}{S} = \frac{0.280 \times 300}{1000}$$

$$= 0.084\text{ U.E. per hour per sq. ft. of heating surface.}$$

$$W = W' - RS = 3145 - 84 = 3061.$$

Formula (11), $$E_a = \frac{BE_p}{1 + \frac{RS}{W}} - A\frac{W}{S} = \frac{0.8807 \times 13.98}{1 + \frac{84}{3061}} - 0.581\,\frac{3061}{1000}$$

$$= 10.205\text{ U.E. per lb. fuel.}$$

Formula (12), efficiency, $$\frac{E_a}{E_p} = \frac{B}{1 + R\frac{S}{W}} - \frac{AW}{SE_p}$$

$$= \frac{0.8807}{1 + \frac{84}{3061}} - \frac{0.581 \times 3061}{1000 \times 13.98} = 0.73.$$

Note.—If the fuel contains hydrogen and water, the values of B and A should be obtained respectively from $\frac{T_1 - t}{T_1}$ and $\frac{acf}{T_1 - t}$ and not from eqs. (8) and (9), since the value of K in these equations, determined from the analysis, is the total heating value, the water in products of combustion being condensed and cooled to the atmospheric temperature. The theoretical value of T_1 may be obtained by the formula given on page 31.

General Formulas for Efficiency.—If in eq. (11),

$$E_a = \frac{BE_p}{1 + R\dfrac{S}{W}} - A\frac{W}{S},$$

we substitute the values of B and A from eqs. (8) and (9), viz.,

$$B = \frac{K - tcf}{K} \quad \text{and} \quad A = \frac{ac^2f^2}{K - tcf},$$

we obtain

$$E_a = \frac{\dfrac{K - tcf}{K}E_p}{1 + R\dfrac{S}{W}} - \frac{ac^2f^2}{(K - tcf)}\frac{W}{S}, \quad . \quad . \quad . \quad . \quad (13)$$

an equation in which, if we consider c, the specific heat of the flue-gases, as a constant, $= 0.24$, there are no less than six variables, viz., K, t, f, r, W/S, and a. For a given fuel and a given steam-pressure in the boiler K and t may also be taken as constants.

Since $E_p = K \div 970.4$, we may write

$$E_a = \frac{K - tcf}{970.4\left(1 + R\dfrac{S}{W}\right)} - \frac{ac^2f^2}{(K - tcf)}\frac{W}{S}. \quad . \quad . \quad . \quad (14)$$

Also the efficiency

$$\frac{E_a}{E_p} = \frac{K - tcf}{K\left(1 + R\dfrac{S}{W}\right)} - \frac{970.4}{K}\frac{ac^2f^2}{(K - tcf)}\frac{W}{S}. \quad . \quad . \quad (15)$$

Interpretation of Equation (13).—For a given fuel, completely burned in the furnace, and a given steam-pressure, the evaporation per pound of combustible will depend—

1. On the heating value of the combustible, or K.

2. On the elevation of the temperature of the water in the boiler above the atmospheric temperature, or t.

3. On f, the weight of flue-gases per pound of combustible, which depends on the force of the draft and on the thickness of the bed of fuel and other obstructions to the draft, such as choked air or gas passages, clinker on the grates, etc.

4. On the rate of driving, W/S, which depends on the quantity of fuel burned per square foot of heating surface.

5. On the loss by radiation, which may be reduced to a small amount by diminishing the extent of radiating surface and by clothing it with non-conducting material.

6. On the value of the coefficient a, which is not merely a coefficient of the resistance to conduction of heat through the metal plates of the boiler, as it has hitherto been considered in theoretical discussions of the subject, but is also a function of the method in which the gases pass over the heating surface, and of the proportion of the whole heating surface which is properly covered by the currents of hot gas as they pass from the furnace to the chimney-flue, not being "short-circuited" or covered by eddies of cool gas. If a boiler has its heating surface of moderate thickness, clean inside and out, and the water on one side has a circulation sufficient to sweep away steam or air-bubbles as fast as they form on it, the value of the coefficient a should be low; but if under these favorable conditions the gas-passages have such an arrangement or such proportions as to allow of the short-circuiting of the current of gas or the formation of eddies of cool gas, then the value of a may be high. It should be noted that the coefficient a as here used is not a "constant of nature" whose value is derived from direct experiments on heat transmission, but is only the result of computation of a complex formula (see eq. 16) which contains six other variables. Any error in the observed data which affects the value of any of these variables will therefore affect the computed value of a.

Large values of f, R, and W/S indicate losses of heat due respectively to excessive supply of air, to excessive radiation, and to excessive rate of driving. A large value of a indicates a loss of heat which may be due to one or more of several causes, such as excessive thickness or defective conducting power of the metal, coatings of scale or grease on one side of the metal, or of soot or dust on the other, short-circuiting of the gases, or imperfect combustion. The multifariousness of this coefficient, therefore, may cause it to have a very wide range of values, say from 100 to 600, instead of the narrow range, 160 to 200, given by Rankine.

The Coefficient a as a Criterion of Boiler Performance.—If we have the following data obtained from the test of a boiler:

K = heating value per lb. of combustible;
W/S = evaporation per sq.ft. of heating surface per hour;
t = temperature of the steam;
E_a = evaporation from and at 212° per lb. combustible,

we may form an approximate estimate of whether or not the performance is high for the given rate of driving by the following method:

From formula (14) we obtain

$$a = \left[\frac{K - tcf}{970\left(1 + R\frac{S}{W}\right)} - E_a\right] \div \frac{c^2f^2}{(K - tcf)}\frac{W}{S}. \quad . \quad . \quad (16)$$

For a high evaporation with given values of K, t, and W/S it is necessary that f and R be low, say $f = 20$ and $R = 0.1$. Substituting these values in the above equation and taking $c = 0.24$, we obtain

$$a = \left[\frac{K - 4.8t}{970\left(1 + 0.1\frac{S}{W}\right)} - E_a\right] \div \frac{23.04}{(K - 4.8t)}\frac{W}{S}. \quad . \quad (17)$$

If, on substituting in this equation the observed values of K, t, W/S, and E_a, the value of a comes between 200 and 400, the performance may be considered high; if much above 400, it is from fair to low. The cause of low performance may be low temperature of furnace, due either to imperfect combustion or to excessive air-supply; short-circuiting of the gases, rendering the heating surface ineffective; air-leaks into the setting; moisture in the coal or in the air; unclean heating surface; or excessive radiation. Examples of the use of this criterion will be found in the chapter on Results of Steam Boiler Trials.

Effect on E_a of Variations of f, R, $\frac{W}{S}$, and a.—We shall now make some computations of different values of E_a, or the evaporation from and at 212° per pound of combustible, based on assumed constant values of K, t, and c, and various values of f, R, a, and W/S. Assume that the coal is anthracite, with a heating value of $K = 14{,}800$ B.T.U. per lb. combustible; that $t = 300°$, corresponding to steam of 140 lbs. gauge pressure, and atmospheric temperature of 60°; and c, the specific heat of the flue-gases, $= 0.24$. Then $tc = 72$;

$$E_p = 14{,}800 \div 970.4 = 15.251;$$

$$E_a = \frac{\dfrac{14{,}800 - 72f}{14{,}800}}{1 + R\dfrac{S}{W}} \times 15.251 - \frac{.0576af^2}{14{,}800 - 72f} \times \frac{W}{S}.$$

Now assume that $f = 20$ and $a = 200$, and with four different values of R, viz., 0, 0.05, 0.1, and 0.2, calculate the effect of radiation upon the values of the actual evaporation per lb. combustible, E_a, and the efficiency, $E_a \div E_p$, for different rates of driving, $W \div S$. The results are as below:

Values of E_a and E_a/E_p with $K=14,800$, $t=300$, $f=20$, $a=200$.

$W/S=$		1	2	3	4	6	8
$R=0$,	E_a =lbs.	13.422	13.077	12.732	12.387	11.698	11.008
"	$E_a/E_p=\%$	88.01	85.74	83.48	81.22	76.70	72.18
$R=0.05$,	E_a =lbs.	12.767	12.742	12.507	12.217	11.583	10.923
"	$E_a/E_p=\%$	83.71	83.55	82.01	80.11	75.95	71.62
$R=0.1$,	E_a =lbs.	12.171	12.422	12.292	12.052	11.473	10.838
"	$E_a/E_p=\%$	79.80	81.45	80.60	79.02	75.23	71.06
$R=0.2$,	E_a =lbs.	11.128	11.823	11.872	11.732	11.258	10.673
"	$E_a/E_p=\%$	72.97	77.54	77.84	76.93	73.82	69.98

To determine the effect of various values of f, or the weight of dry chimney-gases per pound of combustible, upon the evaporation and efficiency, take $R = 0.1$, $a = 200$, and $f = 20$, 25, 30, and 35. The computation gives the results below:

Values of E_a and E_a/E_p with $K=14,800$, $t=300$, $R=0.1$, $a=200$, $f=20$ to 35.

$W/S=$		1	2	3	4	6	8
$f=20$,	E_a =lbs.	12.171	12.422	12.292	12.052	11.473	10.838
"	$E_a/E_p=\%$	79.80	81.45	80.60	79.02	75.23	71.06
$f=25$,	E_a =lbs.	11.625	11.651	11.302	10.855	9.854	8.800
"	$E_a/E_p=\%$	76.22	76.39	74.11	71.11	64.61	57.70
$f=30$,	E_a =lbs.	11.021	10.765	10.145	9.428	7.891	6.303
"	$E_a/E_p=\%$	72.26	70.59	66.52	61.82	51.74	41.33
$f=35$,	E_a =lbs.	10.356	9.754	8.799	7.751	5.553	3.306
"	$E_a/E_p=\%$	67.90	63.96	57.69	50.82	36.41	21.68

In like manner, we obtain the effect of variations in the value of the coefficient a as follows:

Values of E_a and E_a/E_p with $K=14,800$, $t=300$, $R=0.1$, $f=20$, $a=100$ to 400.

$W/S=$		1	2	3	4	6	8
$a=100$,	E_a =lbs.	12.344	12.767	12.810	12.742	12.507	12.217
"	$E_a/E_p=\%$	80.94	83.71	83.99	83.58	82.01	80.11
$a=200$,	E_a =lbs.	12.171	12.422	12.292	12.052	11.473	10.835
"	$E_a/E_p=\%$	79.80	81.45	80.60	79.02	75.23	71.06
$a=300$,	E_a =lbs.	12.000	12.077	11.775	11.362	10.438	9.458
"	$E_a/E_p=\%$	78.68	79.19	77.21	74.50	68.44	62.02
$a=400$,	E_a =lbs.	11.826	11.732	11.258	10.673	9.403	8.078
"	$E_a/E_p=\%$	77.54	76 93	73.82	69.98	61.65	52.97

The values of the efficiency E_a/E_p given in the tables are plotted in the diagrams on the following pages.

The Effect of Variation in the Steam-pressure, giving different values of t, the elevation of the temperature of the steam above that of the atmosphere, is shown below:

Values of E_a and E_a/E_p with $K=14{,}800$, $f=20$, $R=0.1$, $a=200$, and $t=150°$, 250°, and 300°, corresponding respectively to steam-gauge pressures of 0, 65, and 142 lbs., and atmospheric temperature of 62° F.

$W/S=$		1	2	3	4	6	8
$t=150°$, E_a	=lbs.	12.863	13.164	13.059	12.847	12.308	11.712
"	$E_a/E_p=\%$	84.34	86.32	85.63	84.24	80.70	76.79
$t=250°$, E_a	=lbs.	12.402	12.669	12.547	12.318	11.752	11.132
"	$E_a/E_p=\%$	81.32	83.01	82.27	80.77	77.06	72.99
$t=300°$, E_a	=lbs.	12.171	12.422	12.292	12.052	11.473	10.838
"	$E_a/E_p=\%$	79.80	81.45	80.60	79.02	75.23	71.06

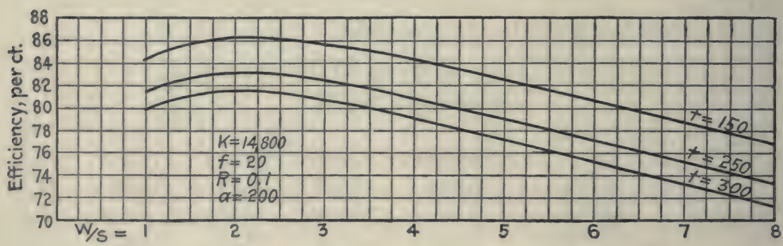

FIG. 76.—EFFECT OF STEAM-PRESSURE UPON EFFICIENCY.

Effect of Heating Value of Fuel on Efficiency.—The value of K, or B.T.U. per lb. combustible, may vary from about 20,000 for petroleum to about 6000 for wood. The formula (13) will not apply without modification to either of these fuels, since another term would have to be subtracted, representing the heat lost in the superheated steam in the chimney-gases, derived from the combustion of the hydrogen in both fuels and from the moisture in the wood. Neglecting this subtractive term and taking two hydrogenous coals, one with a heating value of 16,000 B.T.U. per lb. combustible, about the highest figure for semi-bituminous coal, and the other with 13,600 B.T.U., corresponding to a highly volatile Illinois coal, assuming $f=20$, $a=200$, $c=0.24$, $t=300$, and substituting these values in equation (13), we obtain the following:

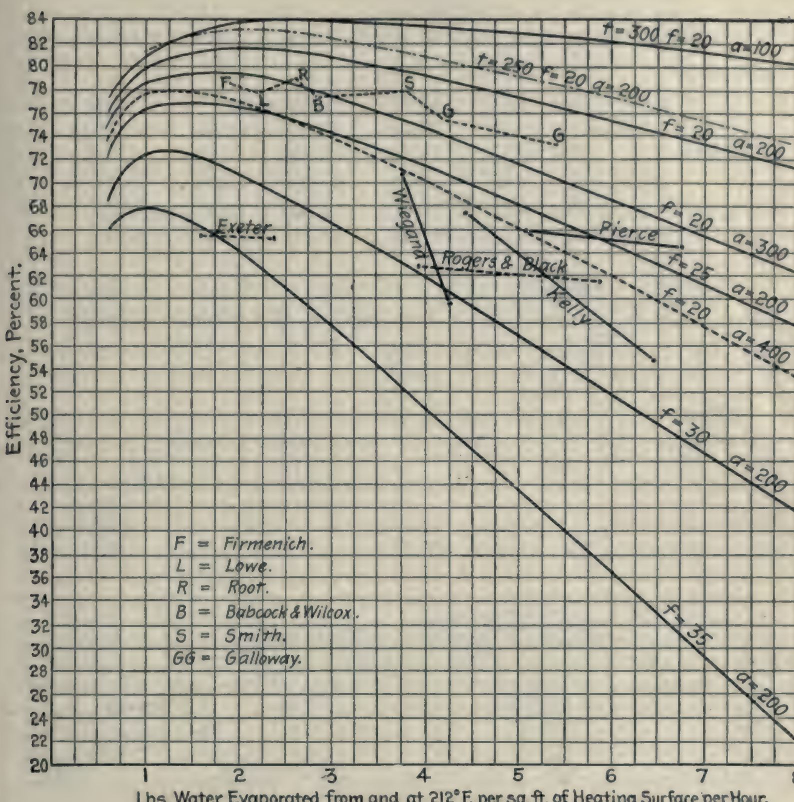

Fig. 77.—Curves of Calculated Efficiencies for Different Rates of Driving, for $K = 14{,}800$, $R = 0.1$, $t = 300$ (except one curve, $t = 250$) $f = 20$ to 35, $a = 100$ to 400.

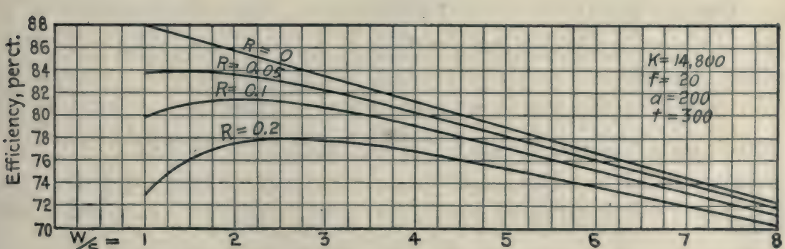

Fig. 78.—Effect of Radiation upon Efficiency.

Values of E_a and E_a/E_p corresponding to $K=13{,}600$, 14,800, and 16,000, no allowance being made for heat lost in superheated steam in the chimney-gases.

$W/S=$		1	2	3	4	6	8
$K=13{,}600$, E_a	=lbs.	11.013	11.176	10.989	10.709	10.051	9.344
"	$E_a/E_p=\%$	78.58	79.74	78.41	76.34	71.72	66.67
$K=14{,}800$, E_a	=lbs.	12.171	12.422	12.292	12.052	11.473	10.838
"	$E_a/E_p=\%$	79.80	81.45	80.60	79.02	75.23	71.06
$K=16{,}000$, E_a	=lbs.	13.325	13.656	13.576	13.372	12.859	12.287
"	$E_a/E_p=\%$	80.82	82.82	82.34	81.10	78.00	74.52

This table shows that, other conditions being equal, the highest efficiency may be obtained from the fuels of the highest heating value; also that the decrease of efficiency due to rapid rates of driving is greatest with fuels of the lowest heating value.

Effect of Hydrogen and Moisture.—For hydrogenous fuels and fuels containing moisture some deduction, amounting usually to upwards of 4%, must be made from the possible efficiency calculated by the formula, on account of loss due to superheated steam in the chimney-gases. The highest efficiency therefore will be obtained from

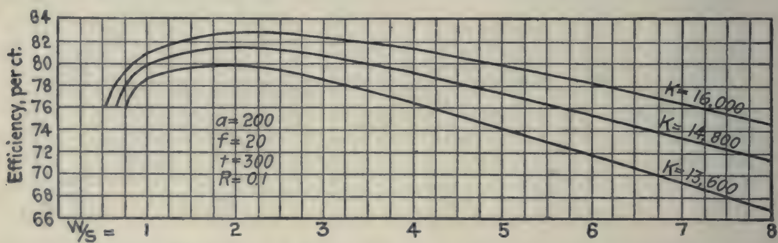

FIG. 79.—EFFECT OF HEATING VALUE OF COAL UPON EFFICIENCY.

anthracite, although the semi-bituminous coals have a higher heating value than anthracite. (See Relation of Quality of Coal to Economy, page 77.)

Loss of Efficiency due to Moisture in Air.—Each pound of air supplied to the furnace carries with it a quantity of vapor of water, which depends on the temperature of the air and its relative humidity. The following figures show the amount of moisture in 1 lb. of air that is fully saturated at the several temperatures named:

Temp.° F.......	32	42	52	62	72	82	92	102	112	122
Moisture, lb.....	.00374	.00555	.00812	.01171	.01669	.02353	.03288	.04555	.06281	.08629

Each pound of water vapor has a total heat (including latent heat) above water at 32° of from 1073.4 B.T.U. at 32° to 1113.4 at

122°. Assuming that the vapor is carried into the chimney flue as superheated steam at 612° F., each pound then has a total heat of 1336.4, and the differences between the heat per pound when supplied to the furnace and when passing into the flue are as follows:

Initial Temp.° F.	32	42	52	62	72	82	92	102	112	122
Gain in heat at 612°, B.T.U.	263	258.6	254.1	249.6	245.2	240.7	236.3	231.9	227.4	223

Multiplying these figures by the moisture per pound of saturated air gives the B.T.U. lost per pound of saturated air. Multiplying the product by the number of pounds of air supplied per pound of fuel gives the B.T.U. loss per pound of fuel due to moisture in the air, if the air is saturated, relative humidity = 100%; and dividing this product by the heating value per pound of fuel gives the loss of efficiency. Taking the heating value per pound of fuel at 15,000, the temperature of the chimney gas at 612° F., and the pounds of air supplied per pound of fuel at 12, 16, 20 and 24, the air being saturated, we obtain the following:

PER CENT LOSS OF EFFICIENCY DUE TO MOISTURE IN SATURATED AIR.

Temp.° F.	32	42	52	62	72	82	92	102	112	122
Air per lb. fuel....... 12	0.08	0.11	0.17	0.23	0.33	0.45	0.62	0.85	1.14	1.54
" " " 16	0.11	0.15	0.22	0.31	0.44	0.60	0.83	1.13	1.52	2.05
" " " 20	0.13	0.19	0.28	0.39	0.55	0.76	1.04	1.41	1.90	2.57
" " " 24	0.16	0.23	0.33	0.47	0.66	0.91	1.24	1.69	2.29	3.08

For lower humidity than 100% the loss will be proportionately lower.

For lower heating value of the fuel than 15,000 the loss will be proportionately higher.

Conclusions from a Study of the Diagrams.—The values of efficiency given in the tables on pages 297 to 300 are plotted on the diagrams accompanying them. In Fig. 77 there are also plotted the values of the highest results obtained at different rates of evaporation in the boiler tests at the Centennial Exhibition (Philadelphia, 1876), and, for comparison, some of the lowest results at different rates of evaporation in the same tests.

A study of the diagrams leads to several important conclusions:

1. The results of seven Centennial tests, *F, L, R, B, S,* and *GG*, which are the highest reliable results ever obtained with anthracite coal for the rates of evaporation shown, lie a little below the curve of $R = 0.1, f = 20, a = 200$.

2. The curve of $R = 0.1$, $f = 20$, and $a = 100$, lies so much above the curve of these Centennial tests as to make the value $a = 100$ highly improbable.

3. The effect of radiation on the evaporation is comparatively small for values of R between 0.05 and 0.2 (which is probably as high a range as is found in practice when the boilers are well covered) when the rate of evaporation is over 3 lbs. per square foot of heating surface per hour, but it increases rapidly at low rates of evaporation.

4. The effect of variations of a within the limits of $a = 100$ and $a = 300$ increases rapidly with the increase of rate of evaporation; but the effect of increase of a is not nearly so important as the effect of increase of f.

5. The effect of increase of f, which is a measure of the air-supply per pound of combustible, is of extreme importance, especially at high rates of driving. With $R = 0.1$ and $a = 200$ the effect on E_a of increase of f with different values of W/S is shown in the following figures:

	$f=20$	$f=30$	$f=35$
$W/S=2$, $E_a=$	12.42	10.76	9.75
" $=4$, " $=$	12.05	9.43	7.75
" $=6$, " $=$	11.47	7.89	5.55

A value of $f = 20$, corresponding to 19 lbs. of air supplied per pound of combustible, is about as low as can be obtained in practice without incomplete combustion of a part of the fuel, resulting in some CO in the furnace-gases. The rapid decrease in economy as the air-supply is increased shows how important it is to so regulate the thickness of the bed of coal, as related to the force of draft, as to keep the supply of air at or near 19 lbs. per lb. of combustible.

Value of c.—In all the above calculations we have taken c, the specific heat of the flue-gases, as constant, $= 0.24$. The actual specific heat of a mixed gas is found by multiplying the percentage by weight of each constituent by its specific heat, adding the products and dividing by 100. The specific heats of the constituents of flue-gases are, according to Regnault, O, 0.2175; N, 0.2438; CO, 0.2479; CO_2, 0.217. The calculated specific heat of flue-gases usually ranges between 0.235 and 0.24. If 0.235 were used instead of 0.24 in computations of eq. (13), the results would be higher by about half of one per cent. It is probable, however, that the figures for the specific heat of the constituent gases given above, which are those

given in most text-books as the specific heats of gases at ordinary atmospheric temperatures, are much too low for hot gases.

If the specific heat is taken a variable increasing as some function of the temperature, the computation would be extremely difficult. In view of the inexactness of the two assumptions made in establishing formula (13), viz., that the transmission of heat is proportional to the square of the temperature difference (between the hot gases and the water) and 2, that the specific heat of the gases is a constant, the formula and the tables and diagrams derived from it should be considered only as empirical and tentative. The results obtained from it, however, show a remarkable agreement with the best results obtained in modern boiler practice.

See Appendix, Note 6, page 340.

Practical Conclusions derived from the above Theoretical Discussion.—Many important deductions may be made from a study of the figures derived from equation (13) and of the diagrams plotted therefrom. It may be well first to restate the notation of that formula:

E_a = lbs. water actually evaporated from and at 212° (or U.E.) per lb. of combustible;

E_p = theoretically possible evaporation in U.E. per lb. of combustible, $= K \div 970.4$;

E_a/E_p = efficiency, usually expressed as a percentage;

K = heating value of the fuel, in B.T.U. per lb. combustible;

t = temperature of the water in the boiler, minus the temperature of the air-supply;

c = specific heat of the gases, taken as a constant = 0.24;

f = lbs. of gas per lb. of combustible;

R = radiation, in U.E. per sq.ft. of heating surface per hour;

W/S = rate of driving, U.E. per hour per sq.ft. of heating surface;

a = an experimental coefficient expressing the resistance of the plates and tubes of the boiler to the transmission of heat, together with certain losses of efficiency due to short-circuiting of the gases, to eddies of cool gas, etc.

The formula is

$$E_a = \frac{\dfrac{K - tcf}{K}}{1 + R\dfrac{S}{W}} E_p - \frac{ac^2f^2}{(K - tcf)}\frac{W}{S} \quad . \quad . \quad . \quad . \quad (13)$$

The first deduction from the study already made is that the efficiency of a boiler is an exceedingly variable quantity, depending on no less than six variable factors, K, t, f, R, W/S, and a. Only one of these factors, viz. a, is related to the construction of the boiler and to the condition of its heating surface, and this only partly, for to some extent it depends on the rate of driving, since short-circuiting of the currents of hot gas may be influenced by the rate of driving. The value of R depends upon the effectiveness of the protection of the boiler and furnace from loss by radiation. All of the other factors are functions of the conditions under which the boiler is operated.

The importance of the factor a upon the efficiency, as shown in the diagram Fig. 77, leads to the conclusion that, so far as possible, the metal of the heating surfaces should be thin; they should be kept clean inside and out; the gas-passages should be so constructed that the currents of hot gas will pass uniformly over the whole extent of heating surface, avoiding short-circuiting and eddies, or the passage at greater speed over some portions than over others; the circulation of water should be sufficient to wipe off bubbles of air or steam as fast as formed; and the combustion should be complete.

The effect of K on the efficiency, as shown in Fig. 79, indicates that the heating value of a fuel is not exactly a measure of its practical value. For a rate of driving $W/S = 3$ we have found, with $f = 20$ and $a = 200$, the values of K being per lb. combustible:

For $K=$	13,600	14,800	16,000
$E_a/E_p=$ per cent	78.41	80.60	82.34
$K\times E_a/E_p=$	10,664	11,929	13,174
While the heating values are in the ratio	91.9	100	108.1
The practical values are in the ratio	89.5	100	110.4

If coal of 14,800 B.T.U. per lb. is worth $1 per ton, coal of 13,600 B.T.U. is worth, not 91.9 cents, but 89.5 cents, if the rate of driving of the boiler is 3 lbs. per sq.ft. of heating surface per hour, and still less if the rate is greater.*

The effect of the rate of driving, W/S, shown in the diagrams, indicates that for practically all values of the other variables the

* The calculation is based on $f=20$ in each case. The coal of $K=13,600$ would be high in oxygen and water, and with it f might be less than 20 without causing CO in the gases. A lower value of f would cause the efficiency to be higher than in the figure given in the table. The coal of $K=16,000$ would be high in hydrogen, which would cause a decrease in efficiency of about 3 to 4%.

evaporation and the efficiency are a maximum when the rate of driving is about 2 lbs. evaporation per sq. ft. of heating surface per hour; but that under fairly good conditions, as when $f = 20$, $a = 200$, the efficiency is but slightly less at 3 lbs. If 3000 lbs. of water per hour are to be evaporated, a boiler of 1000 sq. ft. of heating surface will be almost as economical of fuel as one of 1500 sq. ft., provided the boiler is well constructed, so that a may be 200 or less, the coal is of good quality, say $K = 14{,}800$, and the management of the fire and draft good, so that $f =$ about 20; but if these conditions are unfavorable, then the boiler of 1500 sq. ft. may be much more economical than one of 1000 sq. ft. When good operating conditions are obtainable the small saving in fuel by the larger boiler will probably be more than offset by its greater cost, so that practically boilers proportioned for a rate of driving of 3 lbs. per sq. ft. of heating surface per hour will give about the maximum economy of all costs, including interest on investment, depreciation, etc. When fuel is of very low cost, as near a coal-mine, or when a boiler is to be run at full capacity only a few hours per day, as in electric-lighting plants, boilers proportioned for a much higher rate of driving may be the most economical in total cost.

The effect of R on evaporation is seen to be very slight at all rates of driving above 2 lbs., but it increases rapidly at lower rates. When the rate is below $1\frac{1}{2}$ lbs., and there are two boilers in a plant, it will usually pay to shut down one of them, driving the other at a 3-lb. rate, thereby saving half of the loss due to radiation.

The effect of high values of f, or excessive air-supply, is seen to be more important than that of any other of the variable factors in the equation. It is therefore of the utmost importance to so regulate the draft and the firing that the air-supply shall be no more than sufficient to maintain complete combustion. A very high furnace temperature is generally an indication of the best furnace conditions, although it is possible to have a high temperature and a considerable loss of heat due to incomplete combustion. (See the table on page 28 and the diagram, Fig. 1, on page 29.)

The effect of the temperature of the water in the boiler upon the efficiency is not important within the limits of ordinary steam-boiler practice; but a gain of about 8 per cent in the evaporation, when the rate of driving is about 3 lbs. per sq.ft. of heating surface per hour, might be effected if it were possible to have the water in the boiler of a temperature as low as 212° F. Boiler-tests have sometimes been

made with the water evaporated at atmospheric pressure. Records of efficiency obtained in such tests are not a fair measure of the efficiency which would be obtained at customary steam-pressures. The Centennial tests were made with steam of 70 lbs. gauge pressure, corresponding to $t =$ about 250°. If they had been made with steam of 140 lbs., the evaporation per lb. of combustible would probably have been 0.25 lb. less in those tests which gave the highest results, reducing their record of about 12 lbs. from and at 212° per lb. combustible to about 11.75 lbs.

Results corresponding to $f = 20$ and $a = 200$, and an efficiency of 80 per cent are rarely possible. The highest results obtained in the Centennial tests are shown on the plotted diagram, and no higher results with anthracite have ever been obtained in competitive tests made by disinterested experts since 1876: all fall below 80% efficiency, and considerably below the plotted line of $f = 20$, $a = 200$, and $t = 250°$. It is possible to obtain a value of a as low as 200 in a boiler so designed and proportioned as to avoid all short-circuiting of the gases, and it is also possible to obtain nearly perfect combustion with f as low as 20 lbs. per lb. of combustible, but it is difficult to have both f and a at these low values at the same time. Boilers must be designed with flues or other gas-passages of ample area to insure against choking of the draft, and to allow of the boiler being driven beyond its normal rating, but large gas-passages are apt to lead to more or less short-circuiting, hence to inefficiency of some portions of the heating surface, corresponding to high values of a. The line on the diagram $f = 20$, $a = 200$, must therefore be considered as one which may sometimes, under the most favorable conditions, be nearly but never quite reached, and an efficiency of 80 per cent as a little beyond the best result that may be reached in practice. With semi-bituminous and bituminous coal there is a necessary loss of efficiency due to the hydrogen in the coal, and the consequent loss of heat in superheated steam in the chimney-gases. This loss is rarely less than 3%. We may therefore conclude that about 79% is the highest efficiency that can be reached in practice using hand-fired furnaces, with anthracite coal and 76% with bituminous or semi-bituminous.

Much higher figures than these are sometimes published, but they are due either to errors in the boiler test or to too low figures for the heating value of the coal.

With mechanical stokers and with the air-supply controlled in accordance with the indications of gas analyses 82% may be considered

the maximum limit of efficiency in boilers not provided with economizers.

The theoretical values of efficiency given in the foregoing tables and plotted on the diagrams are all based on the supposition that the combustion is perfect and that the air-supply and the furnace temperature are constant. It is impossible to realize these conditions with hand-firing, since the opening of the fire-door and the firing of fresh coal always chill the furnace. The fresh coal, if small in size, checks the air-supply to some extent and tends to make the combustion imperfect for a short time after it is fired. After the fresh coal has been partly burned away the air-supply is apt to be excessive. All these causes tend to make the efficiency less than that given by the theoretical calculation. With automatic stokers, however, and with the air-supply checked by analyses of the chimney-gases, it is possible to obtain greater uniformity of conditions, and consequently a closer approximation to the theoretical efficiencies.

Low Temperature of Furnace may cause High Flue Temperature.—With high rates of driving and excessive supply of air per pound of fuel a large proportion of the heating value of the fuel is used in heating air which is carried into the chimney instead of in generating steam. Excessive air-supply causes not only a low temperature of the furnace, but it may also cause a high temperature of the chimney-gases, as is shown by the following calculation: Take from the above tables the case of $K = 14,800$, $c = 0.24$, $t = 300$, $a = 200$, $R = 0.1$, and $W/S = 6$, with four different values of f, viz.,

$f =$	20	25	30	35
$E_a =$ lbs.	11.473	9.854	7.891	5.553
Efficiency, $E_a/E_p =$ per cent	75.23	64.61	51.74	36.41
Elev. of temp. of fire, $T_1 = K \div cf =$	3083°	2467°	2056°	1762°

We have $\dfrac{E_a'}{E_p} = \dfrac{T_1 - T_2}{T_1}$, whence flue temperature $T_2 = T_1\left(1 - \dfrac{E_a'}{E_p}\right)$, but E_a' is what the evaporation would be if there were no radiation. It differs from E_a, the actual evaporation, by the quantity

$$E_a' - E_a = BE_p - \frac{BE_p}{1 + \dfrac{RS}{W}} - A\frac{W' - W}{S} = \frac{BE_p}{1 + \dfrac{W}{SR}} - AR,$$

(derived from equations 7 and 11). We have, therefore,

For f =	20	25	30	35
$E_a'-E_p$ =	0.195	0.171	0.144	0.112
E_a' =	11.668	10.025	8.035	5.665
$E_a' \div E_p$ = per cent	76.51	65.73	52.68	37.14
$T_2 = T_1(1-E_a'/E_p)$ =	724°	845°	973°	1108°

The calculation assumes that there are no air-leaks through the setting between the furnace and chimney which would lower the temperature of the chimney-gases and decrease the efficiency.

At low rates of driving, excessive air-supply does not cause so great a rise in the flue temperature; thus for $W/S = 2$, and other conditions as above, we have:

For f =	20	25	30	35
E_a =	12.422	11.651	10.765	9.754
$E_a \div E_p$ = per cent	81.45	76.39	70.59	63.96
T_1 =	3083°	2467°	2056°	1762°
$E_a'-E_p$ =	0.624	0.589	0.550	0.507
E_a' =	13.046	12.240	11.315	10.261
$E_a' \div E_p$ = per cent	85.54	80.26	74.19	67.28
T_2 =	446°	487°	533°	577°

Relation of Furnace Temperature to Extent of Heating Surface required for Good Economy.—From the formulæ $E_a' = BE_p - A\dfrac{W'}{S}$, $B = \dfrac{T_1 - t}{T_1}$, and $A = \dfrac{acf}{T_1 - t}$, it is evident that the actual evaporation per pound of fuel, for a given rate of driving W'/S, depends on the furnace temperature T. This temperature depends not only on the quantity of air supplied per pound of fuel, but also on the thoroughness of the combustion effected by it, as well as on the dryness of the coal and air and on the amount of direct radiation. An air-supply of 18 lbs. per lb. of carbon, making nearly 19 lbs. of gas, will usually produce the maximum efficiency, a lesser supply tending to make the combustion imperfect, and a greater causing excessive dilution of the gases, both of which diminish the efficiency. With the proper supply of air, however, combustion may still be imperfect and the temperature low, on account of imperfect mixing of the air with the gas distilled from the coal, irregular firing, too small space for combustion in the furnace, or other causes.

1. Consider a case in which combustion is perfect, with $E_p = 15$, $T_1 = 3000°$, $t = 300$, $a = 200$, $c = 0.24$, $f = 20$, $W'/S = 3$, and radiation negligible.

$$B = \frac{T_1 - t}{T_1} = \frac{3000 - 300}{3000} = 0.9;$$

$$A = \frac{acf}{T_1 - t} = \frac{200 \times 0.24 \times 20}{2700} = 0.356;$$

$$E_a' = BE_p - A\frac{W'}{S} = 0.9 \times 15 - 0.356 \times 3 = 12.432.$$

2. With other conditions the same as above let $T_1 = 2000°$, being reduced by imperfect combustion. Then

$$B = \frac{2000 - 300}{2000} = 0.85; \quad A = \frac{960}{1700} = 0.565;$$

$$E_a' = 0.85 \times 15 - 0.565 \times 3 = 11.055.$$

This is a decrease of over 11 per cent in evaporation.

3. Find the value of W'/S which with $T_1 = 2000°$ will give an evaporation of 12.432.

$$E_a' = BE_p - A\frac{W'}{S}; \quad 12.432 = 0.85 \times 15 - 0.565\frac{W'}{S};$$

whence $W'S = 0.318 - 0.565 = 0.563$.

This means that in order to obtain the same capacity and the same economy combined from a boiler with a furnace temperature of 2000° as can be obtained with 3000°, under the conditions named, it would be necessary to increase the heating surface in the ratio of 3 to 0.563, or over five times. The case is still worse if radiation is taken into account, for the loss by radiation per pound of fuel burned is much greater at very low than at moderate rates of driving. Let r = loss by radiation, in units of evaporation per pound of fuel, then $E_a' + r = BE_p - A\frac{W'}{S}$. If r in the last case $= 0.32$, then $E_a' = 12.43 + 0.32 = 12.75 - 0.565\frac{W'}{S}$, whence $W'/S = 0$; that is, the evaporation of 12.43 U.E. per lb. fuel could not be reached by any enlargement of heating surface whatever if the furnace temperature were as low as 2000°.

4. Suppose the furnace temperature is reduced not by imperfect combustion but by excessive air-supply. Let $f = 30$ lbs. and $T = 2000°$.

$$B = 0.85 \text{ as before; } A = \frac{acf}{T_1 - t} = \frac{200 \times 24 \times 30}{1700} = 0.847;$$

$$E_a = 0.85 \times 15 - 0.847 \times 3 = 10.21 \text{ for } W'/S = 3.$$

5. With $f = 30$, required W'/S to make $E_p = 12.43$.

$$12.43 = 0.85 \times 15 - 0.847\ W'/S;$$

$$W'/S = (12.75 - 12.43) \div 0.847 = 0.37,$$

a figure which would probably be reduced to 0 by radiation.

Examples 3 and 5 show that high furnace temperature is even a more important factor of economy than extent of heating surface.

Effect of Increasing the Heating Surface.—Heat Transmitted by Successive Portions of the Surface.—Suppose we have a horizontal fire-tube boiler, Fig. 80, with an external furnace in which com-

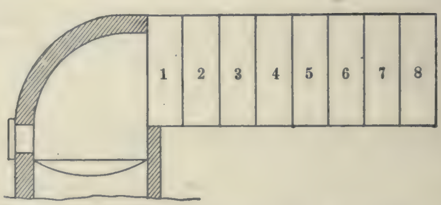

FIG. 80.—BOILER DIVIDED IN SECTIONS.

bustion is completed before the hot gases reach the heating surface. Conceive that the heating surface is divided by vertical planes into a number of equal sections. It is desired to find the temperature at the end of each section, the efficiency of each section in transmitting heat, and the efficiency of the boiler when made of 1, 2, 3, etc., up to 20 sections, the amount of fuel burned per hour being the same in each case.

For convenience of calculation, assume that the boiler has 50 tubes, each of 1 ft. interior circumference, and that each section is 1 ft. long and has 1 sq. ft. of heating surface. The combustible burned per hour is taken at 244 lbs., or 4.88 lbs. for each tube, and its heating value is 14,800 B.T.U. per lb. Assume that the weight of gases per lb. of fuel is 20 and 30 lbs. in two cases considered, that the specific heat of the gases is 0.24, that the temperature of the water in the boiler is 300° F. above the temperature of the atmosphere, and that the value of the experimental coefficient a is 200. Considering only one tube we have then

$K = 14,800$; $F = 4.88$; $c = 0.24$; $a = 200$; $t = 300$; $f = 20$ or 30; $S = 1, 2, 3$, etc., up to 20. Radiation R is taken as 0.

The temperature (above atmospheric) of the gas in the furnace, assuming no loss by radiation, is

$$T_1 = K \div fc = 14{,}800 \div 4.8 \text{ or } 7.2, \ = 3080° \text{ or } 2056°.$$

The efficiency of a boiler of any number of sections, that is, the ratio of the heat transmitted by it to the heat which it receives, may be found by formula (5) $\dfrac{E_a'}{E} = \dfrac{(T_1 - t)^2 \div T_1}{(T_1 - t) + \dfrac{acfF}{S}}$. For the first section, $S = 1$, we have $\dfrac{E_a'}{E_p} = \dfrac{2780^2 \div 3080}{2780 + 4685} = 0.3361$. From equation (1), $\dfrac{E_a'}{E_p} = \dfrac{T_1 - T_2}{T_1}$, whence $T_2 = T_1\left(1 - \dfrac{E_a'}{E_p}\right) = 3080 \times 0.6639 = 2045°$.

For the water evaporated, corresponding to any given efficiency, we have

$$W' = FE_a' = \frac{FE_a'}{E_p} \times E_p; \quad E_p = \frac{K}{970.4} = 15.251; \quad W' = 4.88 \times 15.251 \frac{E_a'}{E_p}$$
$$= 74.427 \frac{E_a'}{E_p}.$$

In the way described above the following results have been obtained:

S	T_2		Efficiency, Per cent		W'		W'/S.	
	$f=20$.	$f=30$.	$f=20$.	$f=30$.	$f=20$.	$f=30$.	$f=20$.	$f=30$.
0	3080°	2056°						
1	2045	1705	33.61	17.08	25.02	12.71	25.02	12.71
2	1571	1471	49.00	28.45	36.47	21.17	18.23	10.59
3	1300	1304	57.79	36.58	43.01	27.22	14.34	9.07
4	1125	1178	63.47	42.70	47.24	31.78	11.81	7.95
5	1001	1079	67.50	47.52	50.24	35.37	10.05	7.07
6	910	1001	70.46	51.31	52.44	38.19	8.74	6.36
7	844	937	72.60	54.43	54.03	40.51	7.72	5.79
8	787	884	74.45	57.00	55.41	42.42	6.93	5.30
9	741	839	75.94	59.19	56.52	44.05	6.28	4.89
10	703	800	77.37	61.09	57.58	45.47	5.76	4.55
12	645	738	79.06	64.11	58.84	47.71	4.90	3.98
14	600	689	80.52	66.49	59.93	49.49	4.28	3.53
16	566	650	81.62	68.39	60.75	50.90	3.80	3.18
18	539	618	82.50	69.94	61.40	52.05	3.41	2.88
20	517	591	83.22	71.25	61.94	53.03	3.10	2.65

The results may be summarized as follows: A boiler is made up of 20 equal sections added one after another. A constant quantity of fuel is burned per hour. When the air supply is such as to make

20 lbs. of gas per lb. of fuel the initial temperature is 3080°, the temperature at the end of the first section is 2045°, and it drops as successive sections are added, to 517; while if the gases are 30 lbs. per lb. of fuel, the initial temperature is only 2056°, but the final temperature at the end of the 20th section is reduced only to 591°.

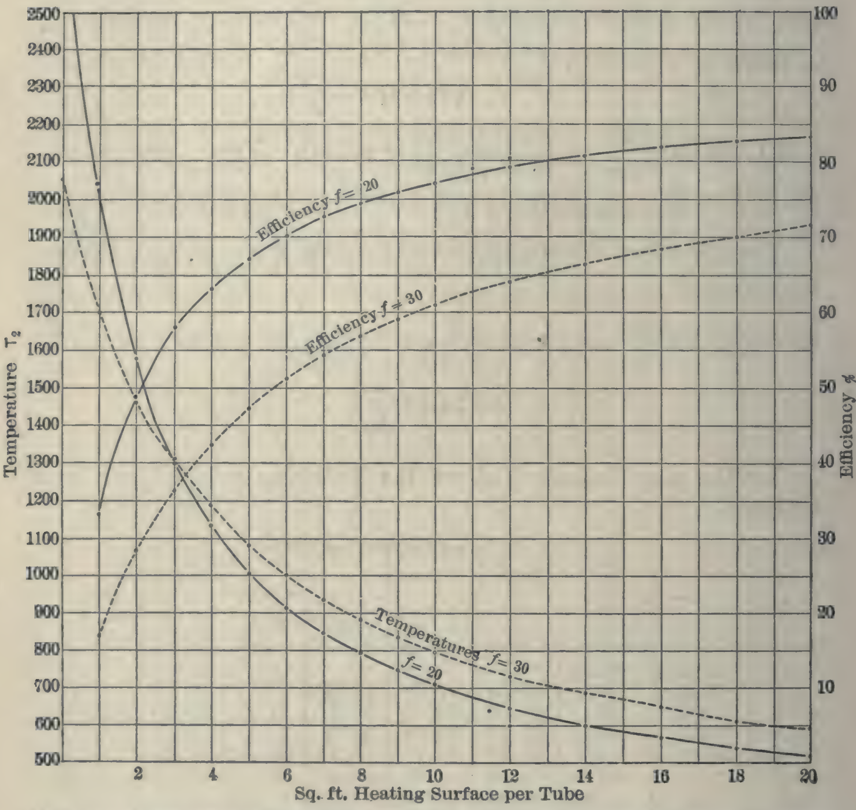

FIG. 81.—INCREASE OF EFFICIENCY AND DECREASE OF FLUE GAS TEMPERATURE DUE TO INCREASE OF HEATING SURFACE.

The efficiency increases as the sections are added, from 33.61% to 83.22% when $f = 20$, and from 17.08% to 71.25% when $f = 30$. Six square feet of heating surface with $f = 20$ gives a greater evaporation and a greater efficiency than 18 sq. ft. when $f = 30$, and 7 sq. ft. when $f = 20$ gives a greater evaporation than 20 sq. ft. when $f = 30$. Increasing the heating surface from 10 to 20 sq.ft. increases the efficiency from 77.37 to 83.22% or 5.85%, when $f = 20$, and from 61.09 to 71.25%, or 10.16% when $f = 30$. With 10 sq. ft. of heating surface, $f = 30$ and efficiency $= 61.09\%$, doubling the heating surface will in-

crease the efficiency to 71.25%, but reducing f to 20, without increasing the heating surface, will increase the efficiency to 77.37%.

The water evaporated per hour increases from 25.02 in one section to 61.94 in 20 sections when $f = 20$, and from 12.71 to 53.03 when $f = 30$. The successive differences in the figures in the columns headed W' show the amount evaporated by each successive section. The last two columns show how the rate of evaporation per square foot of heating surface decreases as the sections are added.

The most important fact to be learned from these results is the great falling off both in capacity and efficiency when the air supply is increased from 19 lbs. to 29 lbs. (corresponding to an increase of

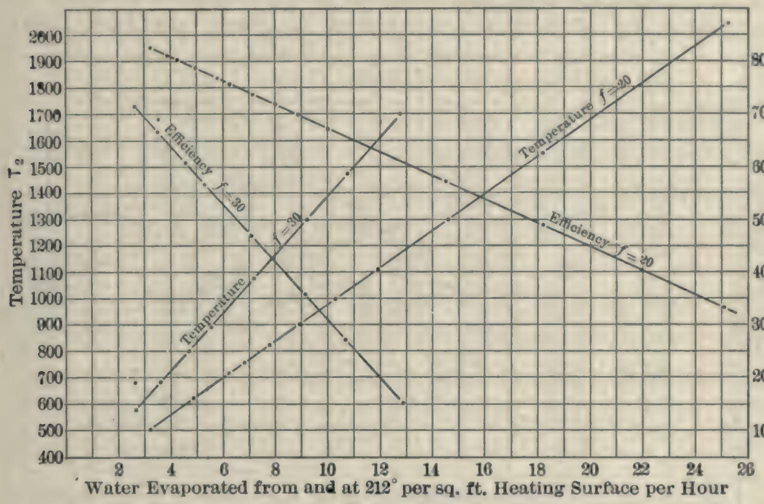

FIG. 82.—RELATION OF FLUE GAS TEMPERATURE AND EFFICIENCY TO RATE OF DRIVING.

f from 20 to 30) per pound of combustible. With $f = 20$ a rate of driving of 4.90 lbs. per sq. ft. of heating surface gives an evaporation of 58.84 lbs. and an efficiency of 79.06%, while when $f = 30$, the same rate of driving (4.89 lbs.) gives an evaporation of only 44.05 lbs. and an efficiency of only 59.19%.

The figures in the table are plotted in Fig. 81, on the basis of the number of square feet of heating surface per tube. The figures for efficiency are plotted also in Fig. 82, on the basis of the rate of evaporation per square foot of heating surface. The efficiency figures for the larger heating surfaces and slower rate of evaporation per sq. ft. of heating surface might be considerably reduced if radiation had been considered.

Chart and Table Showing Efficiencies and Flue Temperatures for Varying Air Supply and Rate of Driving.—Using the same data

as those given above, except that f is taken at 18, 21, 24, 27, 30 and 36 and S at 3, 4, 5, 6, 9 and 12, the following table has been calculated and Fig. 83 plotted therefrom, showing how with a constant weight of fuel but with the heating surface and the air supply varied, the efficiencies, the rates of driving and the flue temperatures vary. With radiation taken at 0, the chart consists of two sets of straight lines crossing each other, one set giving the heating surface and the fuel burned per hour per square foot of heating surface; the other giving the pounds of gas per pound of fuel. At the intersections of these lines are given the flue temperatures corresponding to the several conditions. Two dotted line curves are given in addition, show-

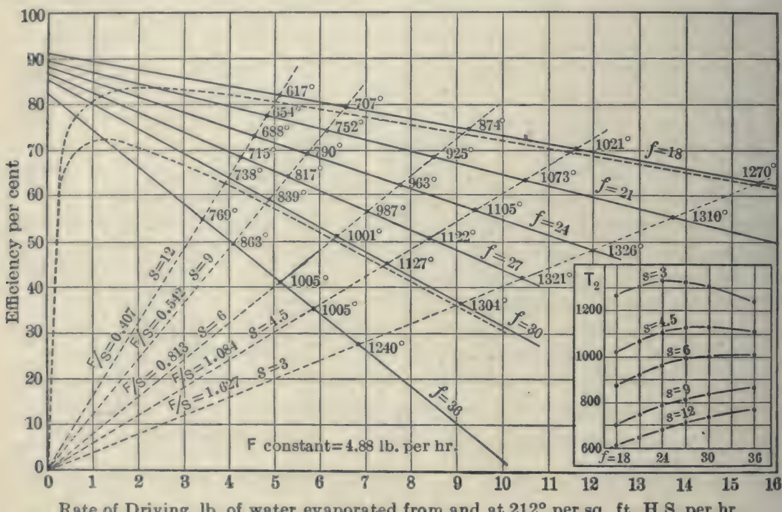

FIG. 83.—EFFECT OF AIR SUPPLY AND RATE OF DRIVING ON EFFICIENCY.

ing the efficiencies with $f = 18$ and $f = 30$ when a radiation factor $R = 0.1$ is used. At the lower right hand of the chart there is a small diagram showing the relation of the flue temperatures, T_2, to the air supply with different amounts of heating surface. With large heating surface, $S = 12$, the temperature increases as the air supply increases, but with small heating surface the temperature is a maximum when f is about 24.

The formulæ required are repeated here for convenience.

Temperature of furnace, $$T_1 = K \div fc,$$

Efficiency, $$\frac{Ea'}{Ep} = \frac{(T_1 - t)^2 \div T_1}{(T_1 - t) + \frac{acfF}{S}},$$

Temperature at the end of any section, $T_2 = T_1(1 - E_a/E_p)$.

Water evaporated, $W' = F\frac{E_a}{E_p} \times \frac{K}{970.4}$.

The chart emphasizes most strongly the fact that high efficiencies can be obtained with high rates of driving only when the air supply is kept at the lowest figure consistent with complete combustion, corresponding to $f = 18$ or thereabouts.

FLUE TEMPERATURES, RATES OF DRIVING, AND EFFICIENCIES, CORRESPONDING TO VARYING EXTENT OF HEATING SURFACE AND VARYING AIR SUPPLY

	$f =$ $T_1 =$	18 3426°	21 2936°	24 2569°	27 2284°	30 2056°	36 1713°
$S = 3$ $F/S = 1.627$	$T_2 =$	1210°	1310°	1326°	1321°	1304°	1240°
	$W_1/S =$	15.61	13.74	12.00	10.46	9.07	6.85
	$E_a/E_p =$	62.94	55.38	48.37	42.16	36.58	27.60
$S = 4.5$ $F/S = 1.084$	$T_2 =$	1021°	1073°	1105°	1122°	1127°	1105°
	$W_1/S =$	11.61	10.49	9.43	8.41	7.48	5.87
	$E_a/E_p =$	70.19	63.45	56.99	50.57	45.21	35.48
$S = 6$ $F/S = 0.813$	$T_2 =$	874°	925°	963°	987°	1001°	1005°
	$W_1/S =$	9.24	8.50	7.75	7.04	6.36	5.13
	$E_a/E_p =$	74.48	68.51	62.51	56.77	51.31	41.35
$S = 9$ $F/S = 0.542$	$T_2 =$	707°	752°	790°	817°	839°	863°
	$W_1/S =$	6.56	6.15	5.73	5.31	4.89	4.10
	$E_a/E_p =$	79.34	74.40	69.26	64.18	59.19	49.60
$S = 12$ $F/S = 0.407$	$T_2 =$	617°	654°	688°	715°	738°	769°
	$W_1/S =$	5.09	4.82	4.56	4.26	3.97	3.42
	$E_a/E_p =$	82.01	77.73	73.21	68.86	64.11	55.10

Modification of Formula (15) for Incomplete Combustion and for Moisture.—Let C, H and M be respectively the percentages of carbon, hydrogen and moisture in a fuel, K the total heating value per pound, and f the pounds of dry gas per pound of fuel. The heat per pound of fuel that is available in the furnace for raising the temperature of the gases of combustion is less than K if part of the C is burned to CO instead of to CO_2 and it is further diminished by the amount of the latent heat of the steam formed from the hydrogen and moisture in the fuel.

The loss of heat per pound of fuel due to incomplete combustion of the carbon is $101.5\,C \times \frac{CO}{CO + CO_2}$, in which CO and CO_2 are respectively percentages by volume of the dry gases. The loss due to the latent heat of steam in the gases is

$$(9H + M) \times 970.4 \div 100 = 970.4(0.09H + 0.01M).$$

We have, therefore, for the available heating value

$$K_1 = K - 101.5\,C\frac{CO}{CO + CO_2} - 970.4(0.09H + 0.01M).$$

The heat lost per pound of fuel in the gases escaping at the temperature (measured above atmospheric temperature) of the water in the boiler, represented in equation (15) by $t\ c\ f$ is increased by the heat of the superheated steam in these gases, measured above the atmospheric temperature t_a, or

$$(0.09H + 0.01M)[212 - t_a + 970.4 + 0.48(t + t_a - 212)];$$

but the loss due to latent heat, 970.4 B.T.U. per lb. steam, has already been taken account of in the furnace losses, and the remaining loss at the temperature $t + t_a$ is

$$(0.09H + 0.01M)(0.48t - 0.52t_a + 110.24).$$

If we take $t = 300$ and $t_a = 62°$ for average conditions, this reduces to

$$(0.09H + 0.01M) \times 222,$$

and $$tcf_1 = tcf + 222(0.09H + 0.01M).$$

If $t = 300$ and $c = 0.24$, $tc = 72$; $222 \div 72 = 3.08$, and we may write

$$tcf_1 = tc[f + 3.08(0.09H + 0.01M),$$

or $$f_1 = f + 0.28H + 0.03M,$$

which is a sufficiently close approximation for all ordinary values of t and t_a.

Formula (15) thus modified for incomplete combustion of carbon and for latent heat of the steam in the gases thus becomes

$$\frac{E_a}{E_p} = \frac{K_1 - tcf_1}{K\left(1 + R\frac{S}{W}\right)} - \frac{970.4}{K}\,\frac{a_1c^2f_1{}^2}{K_1 - tcf_1}\,\frac{W}{S}; \quad . \quad . \quad . \quad (18)$$

and, similarly formula (16) for the value of a becomes

$$a_1 = \left[\frac{K_1 - tcf_1}{K\left(1 + R\frac{S}{W}\right)} - \frac{E_a}{E_p}\right] \div \frac{970.4}{K}\,\frac{c^2f_1{}^2}{K_1 - tcf_1}\,\frac{W}{S}. \quad (19)$$

No account is taken in the above calculation of any loss due to unconsumed hydrogen or hydrocarbons, nor of absorption of heat by decomposition of moisture in the coal by the reaction

$C + H_2O = 2H + CO$. Serious losses may be due to these causes if the air supply is deficient and the furnace temperature low, from the firing of a thick layer of fresh and moist coal, or if the combustible gases are chilled by the surface of the boiler to a temperature below that of ignition. No account, either, has been taken of the loss due to moisture in the air, which is considered on page 300.

Example.—Required the efficiency of a boiler using moist wood as fuel, the wood having the composition, Ash 1; Moisture 24; C, 38; H, 5; O, 32. Heating value per lb. 6168 B.T.U. Let $R = 0.1$, $a_1 = 200$, $C = 0.24$, and $t = 300$. Solve for $\frac{W}{S} = 3$, 4 and 6, and $f = 8$ and 12 lbs. per lb. of wood, $= 10.67$ and 16 lbs. per lb. combustible.

$$f_1 = f + 0.28H + 0.02M = 10.12 \text{ and } 14.12;\ f_1^2 = 102.4 \text{ and } 199.4.$$

$$K_1 = K - 970.4(0.09H + 0.01M) = 5498.$$

Formula (18) $$\frac{E_a}{E_p} = \frac{5498 - 300 \times 0.24 f_1}{1 + 0.1\frac{S}{W} \times 6168} - \frac{970.4}{6168} \times \frac{11.52 f_1^2}{5498 - 72 f_1}\frac{W}{S}.$$

Results	$f = 8$			$f = 12.$		
$\frac{W}{S} =$	3	4	6	3	4	6.
$\frac{E_a}{E_p}$ (per cent) =	63.11	59.93	52.77	46.09	38.77	22.78.

This example shows that there is a rapid loss of efficiency with moist fuel at increased rates of driving when the air supply is even moderately excessive. The theoretical air supply required is $0.38 \times 11.52 + (5 - 4) \times 34.56 = 7.834$; $f = 12$ lbs. is only 53% in excess.

Meaning of the Coefficient a_1.—The coefficient a_1 is an empirical coefficient of performance obtained from the results of efficiency tests in which the following values are known or assumed: (1) the analysis and the heating value of the fuel; (2) the analysis of the waste gases; (3) the rate of driving; (4) the temperature of the water in the boiler above atmospheric temperature; (5) the specific heat of the gases; (6) the loss by radiation; (7) the efficiency. It takes into account the loss due to latent heat of the moisture in the steam formed from the combustion of the hydrogen and the moisture in the fuel, and the loss due to incomplete combustion of the carbon, these losses being computed from the analyses, but does not take

into account losses due to the escape of unburned hydrogen or hydrocarbons, or to moisture in the air. It may be considered as a coefficient of resistance of the boiler surfaces to transmission of heat, and its value will be increased by the coating of these surfaces with scale or soot, and by the short-circuiting of the gases, which renders a portion of the surface ineffective. Its value is, moreover, affected by all the errors of measurement of test and by the errors of analyses and of inaccurate sampling of the fuel and of the gases, and by fuel blown out of the chimney if no record is made of it.

The value of the coefficient is in the neighborhood of 200 when the boiler performance is from good to excellent. Values from 160 to 240 may be obtained in duplicate tests in which all the conditions as far as known are identical, the difference between individual and average values being due probably to errors. Values above 300, if not due to errors, represent defective performance which may be due to short-circuiting or to unclean heating surfaces.

The equation for the value of a_1 may be solved conveniently with the aid of a table of four-place logarithms, as in the following example:

Let $K = 14{,}800$; $K_1 = 14{,}200$; $t = 300$; $c = 0.24$; $f_1 = 18$; $W/S = 3$; $R = 0.1$; $E_a/E_p = 78$ per cent.

$$a_1 = \left[\frac{K_1 - tcf_1}{K(1 + RS/W)} - \frac{E_a}{E_p}\right] \times \frac{K(K_1 - tcf_1)}{970.4c^2 f_1^2\, W/S}.$$

$$\begin{array}{rr}
K_1 - tcf_1 = 12{,}904,\ \log = & 4.1107 \\
\hline
K = 14{,}800,\ \log = & 4.1703 \\
1 + RS/W = 1.033,\ \log = & 0.0141 \\
\hline
\text{Sum} = & 4.1844 \\
\text{Difference} = & \bar{1}.9263 \\
\text{No.} = & 0.8440 \\
\text{Subtract } E_a/E_p & 0.7800 \\
\hline
\text{Quantity in brackets} = & 0.0640 \\
\log. = & \bar{2}.8062 \\
\log.\ K(K_1 - tcf_1) = & 8.2810 \\
\hline
 & 7.0872 \\
\hline
\log.\ 970.4c^2 = & 1.7473 \\
\log.\ f_1^2 = & 2.5105 \\
\log.\ W/S = & 0.4771 \\
\hline
 & 4.7349 \\
\hline
\text{Difference} = & 2.3523 \\
a_1 = & 225
\end{array}$$

Values of a_1 Calculated from Results of Boiler Trials.—From the results of six series of boiler trials, 47 tests in all, the values of a_1 have been computed by means of formula (18). The general results of these trials are given in Chapter XVII. They include 13 tests of Babcock & Wilcox marine boilers built for the U. S. cruisers "Cincinnati" and "Wyoming;" 18 tests of a locomotive at the locomotive testing laboratory of Purdue University, Lafayette, Ind., 11 with bituminous and 7 with semi-bituminous coal; and 16 tests of Stirling boilers at the Delray station of the Detroit Edison Co., 9 with a Roney stoker and 7 with a Taylor stoker. The following table gives the values of a_1 for different rates of driving, W/S, and the values are plotted in Fig. 261, page 622. They justify the use of the figure 200 as the approximate average value of a_1 under the best conditions of modern practice.

VALUES OF a_1 IN 47 BOILER TESTS

Marine Boilers.

Cincinnati.			Wyoming.		
No.	W/S	a_1	No.	W/S	a_1
1	5.18	241	1	3.88	326
2	5.57	209	2	6.43	237
3	8.42	255	3	9.03	175
4	8.75	197	4	10.52	161
6	9.58	359	6	10.52	181
5	10.07	150	5	14.76	145
7	13.67	185			
			Av.	. . . .	204
Av.	. . . .	228	Omitting No. 1	Av.	180
Omitting No. 6	Av.	206			

Locomotive.

Bituminous Coal.			Semi-bituminous Coal.		
No.	W/S	a_1	No.	W/S	a_1
12	7.02	203	18	5.12	197
4	9.43	200	9	7.16	157
11	10.07	154	16	9.30	187
7	10.89	189	15	9.90	193
10	11.26	158	6	10.82	251
8	11.47	196	14	12.77	189
3	11.51	198	13	13.30	210
2	13.08	190			
5	13.18	168	Av.	. . . .	198
1	13.69	205			
Av.	. . . .	186			

Stirling Boiler.

Roney Stoker.			Taylor Stoker.		
No.	W/S	a_1	No.	W/S	a_1
2	2.78	274	10	3.22	251
5	3.24	166	8	3.72	184
16	3.40	184	12	4.18	210
1	3.63	194	7	5.22	207
3	3.92	258	9	5.62	237
6	5.20	291	14	6.40	231
4	5.26	261	11	7.29	256
17	6.67	224			
18	6.75	221	Av....	....	225
Av....	....	230			
Omitt'g 274	and 291, Av.	215			

Calculations of Efficiency by the Revised Formula (18).—Take a Pittsburgh bituminous coal, having a composition, free from sulphur and ash, of 83 C, 5.5 H, 8 O, 1.5 N, and 2 Moisture, and a heating value of 14,908 B.T.U. per lb. fuel = 15,222 B.T.U. per lb. combustible, and assume it to be burned with different quantities of air, as in the table below, we may compute the weight of air supplied per pound of fuel and per pound of carbon, and the analysis by volume of the gases, by the synthetic method shown on page 34, giving results as follows:

Case.	Per cent of C Burned to CO.	Per cent Excess Air.	Dry Gas per lb. Fuel $=f$.	Dry Gas per lb. Carbon.	Analysis of Dry Gas by Volume.			
					CO_2	CO	O	N
(1)..........	0	0	11.60	13.98	18.45	0	0	81.55
(2)..........	0	20	13.83	16.66	15.30	0	3.56	81.14
(3)..........	0	50	17.16	20.67	12.18	0	7.09	80.73
(4)..........	0	100	22.72	27.37	9.10	0	10.57	80.33
A...........	5	0	11.36	13.69	17.85	0.94	0	81.21
B...........	5	20	13.23	15.93	15.18	0.80	3.12	80.90
C...........	10	0	11.12	13.40	17.21	1.92	0	80.87
D...........	20	0	10.65	12.83	15.88	3.97	0	80.15

H_2O in gases per lb. fuel $= 0.09H + 0.01M$, in all cases $= 0.515$. Case (1) is an ideal but not a practicable case, since it is not possible in practice to burn all the C to CO_2 without excess of air. Cases (2), (3), (4), A and B are all within the range of ordinary practice (which sometimes shows 200% or more excess air) and cases C and D represent either the condition of too heavy firing and choked air supply, or the condition existing for a minute or two

after firing of fine moist slack coal, which temporarily chokes the air supply and causes the formation of a great volume of smoky gas.

Cases 2 and A represent the best possible practice, reached only when all conditions are most favorable.

Applying formula (18), we take $K = 14,908$; $t = 300$; $c = 0.24$; $R = 0.1$; $a_1 = 200$; $f =$ the values given in the table; K_1 and $f_1 =$ values given by the formulae in the preceding paragraph, and W/S dif-

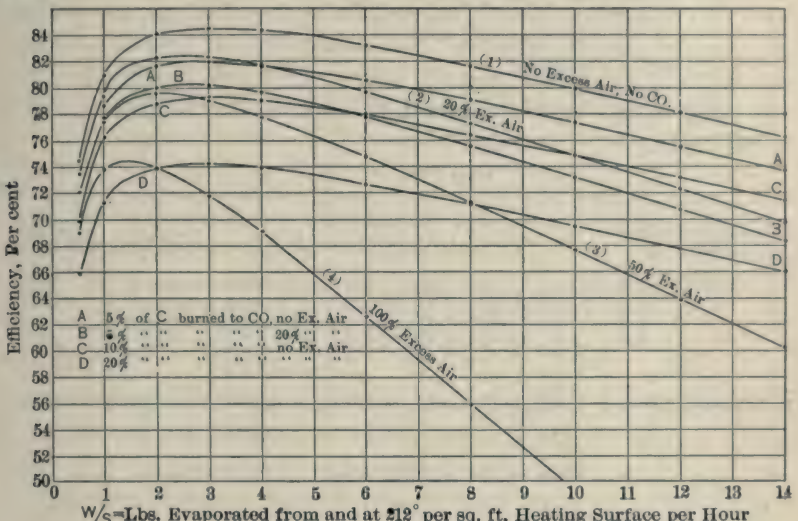

FIG. 84.—THEORETICAL EFFICIENCIES UNDER DIFFERENT CONDITIONS.

ferent values from 0.5 to 14, we obtain the theoretical efficiencies given in the table below:

THEORETICAL EFFICIENCIES WITH PITTSBURGH COAL UNDER DIFFERENT CONDITIONS.

Case......	(1)	(2)	(3)	(4)	A	B	C	D
Per cent C to CO......	0	0	0	0	5	5	10	20
Per cent excess air...	0	20	50	100	0	20	0	0
$W/S=$	EFFICIENCIES, PER CENT							
0.5	74.76	73.68	72.05	68.97	72.53	71.61	69.77	65.79
1	81.13	79.78	77.73	73.72	78.69	77.54	76.23	71.34
2	84.06	82.30	79.60	73.90	81.53	80.02	78.98	73.87
3	84.49	82.34	79.02	71.72	81.91	80.09	79.35	74.16
4	84.24	81.71	77.79	68.91	81.64	79.50	79.09	73.85
6	83.03	79.76	74.65	62.60	80.43	77.65	77.91	72.64
8	81.47	77.45	71.17	55.87	78.87	75.48	76.39	71.11
10	79.77	75.01	67.55	49.20	77.17	73.15	74.74	69.45
12	77.99	72.48	63.86	42.37	75.41	70.76	73.02	67.72
14	76.16	69.92	60.12	35.48	73.58	68.32	71.27	65.97

The figures in the above table are plotted in Fig. 84, which clearly shows the great falling off in efficiency at high rates of driving when the air supply is excessive, and the necessity of gas analysis (or of a CO_2 or an oxygen indicator) if high efficiencies are to be obtained at high rates of driving.

Effect of Quality of Coal upon Efficiency.—Calculations have been made, using formula (18), of the theoretical efficiencies obtainable from five different kinds of coal and an average fuel oil, the analyses of which are given below, on the assumption of complete combustion with 20 per cent excess air supply, $a_1 = 200$, $t = 300$, $c = 0.24$ and rates of driving W/S from 1 to 14 lbs. The results are shown in the table.

ANALYSES OF FUELS

Anthracite Dry and Free from Ash	Semi-bit.	Pittsburgh Ash and S Free.	Illinois.	Lignite.	California Fuel Oil.
C 94.3	Moist. 1.7	Moist. 2.0	Moist. 10.8	Moist. 27.0	0.2
H 2.3	N, S, Ash 4.6	C 83.0	C 61.0	C 47.4	84.9
O 2.4	C 85.0	H 5.5	H 4.2	H 3.3	11.9
N 1.0	H 4.5	O 8.0	O 9.6	O 12.0	1.9
	O 3.2	N 1.0	N 1.2	N 1.0	S 1.1
			Ash, S 13.2		
B.T.U. per lb. 15,000	14,950	14,908	10,640	8250	19,600

RELATION OF EFFICIENCY TO QUALITY OF COAL.

Rate of Driving, W/S	1	2	3	4	6	8	10	12	14
			Efficiencies						
Anthracite...	81.85	84.56	84.71	84.16	82.39	80.25	77.95	75.59	73.19
Semi-bit.....	80.41	82.96	83.00	82.38	80.42	78.10	75.64	73.12	70.54
Pittsbg. bit.	79.78	82.30	82.34	81.71	79.76	77.45	75.01	72.48	69.92
Illinois......	78.28	80.59	80.44	79.64	77.34	74.71	71.93	69.09	66.20
Lignite......	75.83	77.76	77.51	76.52	73.98	70.90	67.79	64.62	61.40
Fuel oil.....	78.78	81.61	82.01	81.74	80.52	78.97	77.26	75.48	73.58

The efficiencies in the above table are plotted in Fig. 85.

Efficiencies Obtained in Practice.—In the best modern practice, under the most favorable furnace conditions, the highest figures in the above tables have almost been reached, as is shown in the chapter on Results of Boiler Tests. A few tests with fuel oil have shown figures slightly higher than those given above. The best record yet obtained with coal is that of the ten best out of the sixteen tests at the Delray station of the Detroit Edison Co., reported by D. S. Jacobus in Trans. A. S. M. E., 1911. A straight line drawn through

the plotting of these tests corresponds to the formula $E = 81 - 1.33 (W/S - 3)$.

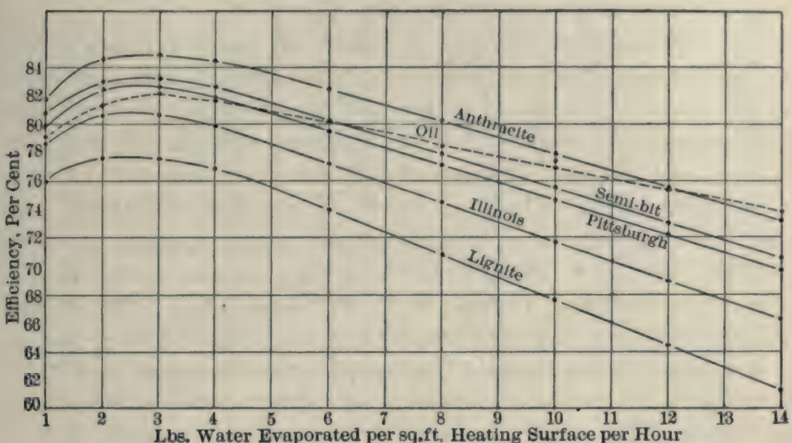

FIG. 85.—RELATION OF EFFICIENCY TO QUALITY OF COAL.

The Straight-line Formula for Efficiency.—An examination of the curves in Fig. 84 shows that when the rate of driving is in excess of 3 lbs. per sq. ft. of heating surface per hour, and the effect of the radiation loss is therefore of small importance, the curves become approximately straight lines, the formula of which is $E = E_{max} - C(W/S - 3)$, in which E is the efficiency at any rate of driving above $W/S = 3$, E_{max} is the efficiency when $W/S = 3$, and C is a constant which depends on the quality of the coal and on the furnace conditions. Taking from the curves on page 321 the efficiencies at $W/S = 3$ and $W/S = 14$ and calculating the value of C in the above equation of a straight line between these points, we obtain the following formulæ for efficiency for the several cases named:

Case	Per Cent C to CO_2	Per Cent Excess Air.	Formula
1	0	0	$E = 84.5 - 0.76(W/S - 3)$
2	0	20	$E = 82.3 - 1.13(W/S - 3)$
3	0	50	$E = 79.0 - 1.72(W/S - 3)$
4	0	100	$E = 71.7 - 3.29(W/S - 3)$
A	5	0	$E = 81.9 - 0.76(W/S - 3)$
B	5	20	$E = 80.1 - 1.07(W/S - 3)$
C	10	0	$E = 79.4 - 0.73(W/S - 3)$
D	20	0	$E = 74.2 - 0.74(W/S - 3)$

Efficiencies calculated from these formulæ, for values of W/S above 3, are in all cases within 1 per cent of those given in the table, always lower, as the curves plotted from the figures in the table lie a trifle above the lines of the straight-line formulæ.

The figures given the table represent the maximum results that can be obtained under the several conditions named, and they make no allowance for moisture in air nor for unburned hydrogen and hydrocarbons. In practice it is not to be expected that figures quite as high as these can be obtained. The nearest approach to them in any long series of tests in which the greatest precautions were taken to secure accuracy, are those given in the report of the tests made by Dr. D. S. Jacobus at the Delray station of the Detroit Edison Co., in 1911. (Trans. A. S. M. E., vol. 33.) The ten best tests out of sixteen give the formulæ $E = 81 - 1.33\ (W/S - 3)$.

The straight line formulæ corresponding to the curves in Fig. 85, showing the theoretical efficiencies with different kinds of fuel are as follows:

Anthracite	$E=84.7-1.05(W/S-3)$
Semi-bituminous	$E=83.0-1.13(W/S-3)$
Pittsburgh bituminous	$E=82.3-1.13(W/S-3)$
Illinois bituminous	$E=80.4-1.29(W/S-3)$
Lignite	$E=77.5-1.46(W/S-3)$
Fuel oil	$E=82.0-0.77(W/S-3)$

Deductions from the Straight-line Formula.—If we take the formula obtained from the ten best tests at Detroit, $E = 81 - 1.33(W/S - 3)$ as representing the maximum results that may be expected from any type of boiler (not provided with an economizer) when all conditions, such as quality and dryness of coal, abundant volume of combustion space, uniformity of depth of fire, air supply, etc., are most favorable, then, by calculation from the formula the following results will be obtained for different rates of driving. It is assumed for the purpose of the calculation that the fuel burned per hour is a constant quantity, sufficient to evaporate 100 lbs. of water per hour from and at 212° if the efficiency = 100%. For any other efficiency the pounds evaporated = per cent efficiency, or $W = E$; then $W = 84 - 1.33W/S$.

In ordinary practice the figures given in the table for E when $W/S = 10$ to 20 can rarely be obtained, on account of the difficulty of providing a sufficiently large volume of combustion chamber for the complete burning of the gases and of providing a grate surface large enough to develop the capacity without having an excessive draft pressure which will blow unburned fuel into the chimney.

RELATION OF EFFICIENCY TO RATE OF DRIVING UNDER BEST FURNACE CONDITIONS.

W/S	S/H.P.	E or W.	S	F	W/F
3	11.50	81.00	27.00	1.235	8.10
4	8.62	79.67	19.92	1.255	7.97
5	6.90	78.34	15.67	1.276	7.83
6	5.75	77.01	12.84	1.299	7.70
7	4.93	75.68	10.81	1.321	7.57
8	4.31	74.35	9.29	1.345	7.43
9	3.83	73.02	8.11	1.369	7.30
10	3.45	71.69	7.17	1.395	7.17
11	3.14	70.36	6.40	1.421	7.04
12	2.87	69.03	5.75	1.449	6.90
13	2.65	67.70	5.21	1.477	6.77
14	2.46	66.37	4.74	1.507	6.64
15	2.30	65.04	4.34	1.537	6.50
16	2.16	63.71	3.98	1.570	6.37
17	2.03	62.38	3.68	1.603	6.24
18	1.92	61.05	3.39	1.638	6.10
19	1.82	59.72	3.14	1.674	5.97
20	1.72	58.39	2.92	1.712	5.84

W/S = evaporation from and at 212° per sq.ft. heating surface per hour.
S/H.P. = sq.ft. of heating surface per horsepower.
E = per cent boiler efficiency.
S = sq.ft. of surface required to evaporate W lbs. when efficiency $= E$.
F = relative quantity of fuel required if 1 lb. represents an efficiency of 100 per cent, = reciprocal of $(E \div 100)$.
W/F = relative water evaporated per lb. of fuel if $W/F = 10$ lbs. when $E =$ 100 per cent.

A. Blechynden's Experiments on Transmission of Heat through plates from hot gases on one side, to water on the other.* In these experiments the water was contained in a cylindrical iron vessel of tinned iron plate, 24 W. G. in thickness, with the steel plate to be tested soldered in the bottom. The vessel, protected from radiation by air-spaces and asbestos felt, was placed above a fire-brick furnace, the lower half of which was filled with asbestos lumps or balls, covered with wire gauze. Jets of gas were burned among these balls, generating a high temperature in the products of combustion in the upper part of the furnace. The hot gases were allowed to escape through four small horizontal pipes at the top of the furnace, on four sides, so that the plate was exposed on its bottom surface to hot gas at a practically uniform temperature.

Experiments were made on five plates of different thicknesses, viz., plate A, originally 1.1875 in. thick, and reduced in four successive operations, by machining, to 0.125 in. thick; plate B, four thick-

* Trans. Inst. Naval Architects, 1894; also Donkin's "Heat Efficiency of Steam-boilers," p. 145.

nesses, from 0.4688 in. thick to 0.1562 in. thick; plate C, 0.8125 in.; plate D, 0.5 in.; plate E, 1.1875 in., and 0.1875 in. Plates A, B and D had one side machined, and the other side (that exposed to the fire) left with the natural surface as it came from the mill. Plate C had both sides untouched, and plate E both sides machined.

The temperature of the furnace was determined by a Siemens copper-ball pyrometer. In some cases an iron ball was used instead. The specific heats of both were compared with that of a piece of platinum, and the temperatures recorded depend upon Pouillet's determination of the specific heat of platinum, as in the following table:

Temp. C.	Temp. F.	Platinum, Sp. Ht. (Pouillet).	Iron, Sp. Ht.	Copper, Sp. Ht.
Between 0 and 100.....	32 and 212	0.0335	0.1095	0.0961
" 0 " 300.....	32 " 572	.0343	.1189	.0997
" 0 " 500.....	32 " 932	.0352	.1279	.1032
" 0 " 700.....	32 " 1292	.0360	.1374	.1068
" 0 " 1000.....	32 " 1832	.0373	......	melts.
" 0 " 1200.....	32 " 2192	.0382	......	......

The following results were obtained in the experiments: $T - t$ being the difference between the temperature F, of the gas below the plate and the water above it, q, the quantity of heat transmitted in British thermal units per hour per square foot, and a, coefficient of transmission calculated from the formula

$$q = \frac{(T-t)^2}{a}, \quad \text{or} \quad a = \frac{(T-t)^2}{q}$$

PLATE A.

Thickness, Inch.									
1.187 $T-t=$	....	....	848	993	1,013	1,213	1,228	1,278
$a=$	....	....	66.6	66.8	66.3	64.7	61.6	61.0
0.75 $T-t=$	....	....	626	788	913	1,058	1,233	....
$a=$	....	....	57.2	56.9	56.9	55.2	56.1	....
0.562 $T-t=$	....	....	563	708	963	1,148	....	....
$a=$	....	....	47.2	49.1	47.7	44.6	....	....
0.25 $T-t=$	....	....	503	646	723	828	893	978
$a=$	....	....	42.6	45.2	44.0	44.5	44.2	42.3
0.125 $T-t=$	738	908	993	1,083	1,123	1,133	1,138	1,318
$a=$	44.7	43.7	41.1	42.5	41.2	41.5	41.3	38.5

PLATE B.

Thickness, Inch.										
0.469	$T-t=$	413	638	643	993	1,028	1,123	1,128	1,148	.....
	$a=$	39.8	44.3	44.2	41.9	41.4	41.1	41.2	41.3	.....
0.375	$T-t=$	650	656	958	968	1,108	1,288	1,308	.....	.....
	$a=$	44.3	41.4	40.9	42.3	41.0	40.0	39.7	.....	.....
0.25	$T-t=$	373	513	773	823	848	855	1,108	1,128	1,268
	$a=$	38.7	40.1	40.7	39.3	39.3	38.4	39.1	38.4	36.7
0.156	$T-t=$	543	738	973	1,058	1,123	1,248	1,263	....	.....
	$a=$	39.0	40.2	38.4	38.7	38.3	38.2	37.4	....	.....

PLATE C.

0.812	$T-t=$	652	763	773	778	778	848
	$a=$	54.9	53.6	52.4	58.0	54.2	57.6

PLATE D.

0.5	$T-t=$ ...	439	755	738	744	768	847	879	910
	$a=$ ...	45.2	43.2	41.6	40.8	42.2	44.3	41.3	40.6

PLATE E.

1.187	$T-t=$	301	440	644	1,073
	$a=$	62.9	70.0	79.4	71.3
0.187	$T-t=$	322	559	743	1,128
	$a=$	52.4	52.1	53.5	51.1

AVERAGE VALUES OF THE COEFFICIENT a.

Plate A, Thickness	1.1875 in.	0.75 in.	0.5625 in.	0.25 in.	0.125 in.
$a=$	64.5	56.5	47.1	43.8	41.9
Plate B, Thickness	0.4687	0.375	0.25	0.156	
$a=$	41.9	41.4	39.0	38.6	
Plate C, Thickness	0.8125				
$a=$	55.1				
Plate D, Thickness	0.5				
$a=$	42.4				
Plate E, Thickness	1.1875	0.1875			
$a=$	71.9	52.3			

Mr. Blechynden says: "The broad general fact is evident that the heat transmitted through any of the plates per degree of difference of temperature of the water and the fire is proportional to that difference; or in other words, the heat transmitted is proportional to the square of the difference between the temperature at the two sides of the plate, or

$$\frac{\text{Heat transmitted per sq. ft.}}{(\text{Difference of temperature})^2} = \text{a constant}$$

for each plate within the limits of the experiments."

Mr. Blechynden gives this constant, or modulus, for each plate. It is the reciprocal of the coefficient a, which has been calculated by the author from the average results, for the purpose of comparing it with the similar coefficient used by Rankine and others, and adopted in the preceding discussion on the efficiency of heating surface.

Mr. Blechynden further says: "The table shows that there is a general rise in the value of the moduli [a decrease of a] with decrease of thickness, but there are considerable irregularities in the curves joining the various points for each plate. This is perhaps no more than might be expected, because of the great difficulty of machining all the surfaces to the same degree of smoothness, and notwithstanding the precautions taken, the difficulty in maintaining the surfaces uniformly clean. It was found that the very slightest traces of grease caused a very large fall in the rate of transmission; even wiping the surface of the plate with a piece of rag or waste was sufficient to influence the result detrimentally. That the smoothness of the surfaces was an important factor will be readily seen when the position of the points for the plate E are compared with the others. The differences are due to A and B having the same receiving surface as from the mill, while E was very smoothly machined.

"The results of these experiments certainly point to the conclusion that the thinner the plates forming part of the heating surface of a boiler the higher should be the boiler efficiency, always provided that the plates are clean, but it will be evident that if the plates be coated with a covering of scale, or some bad conductor, then the less must be the influence of the thickness on the efficiency, while with a thick coat of oil the influence might become practically unimportant. The fact that the heat transmission is proportional to the square of the difference of temperature of the two sides of the plate shows the importance of high furnace temperatures."

The average values of the coefficient a obtained from Blechynden's experiments have been plotted in the adjoining diagram, Fig. 86. It will be seen that each plate has a law of rate of transmission of its own. Plates A and C have about the average values for the different thicknesses, and a line plotted from the formula $a = 40 + 20t$ is near to all the values obtained from plate A. The formula $a = 40 + 20t \pm 10$ covers the whole range of the experiments.

The very low values of a deduced from Blechynden's experiments, viz., 38.6 to 71.9, as compared with the values 200 to 400, commonly obtained in steam-boiler tests, are no doubt due to the exceptionally

favorable conditions under which his experiments were made, all portions of the plate being clean and equally exposed to radiation and to contact with the hot gases, while in steam-boilers only a small fraction of the heating surface receives radiation from the incandescent fuel or from glowing fire-brick, the surface is apt to be more or less covered with soot, dust, scale, or grease, and the whole heating

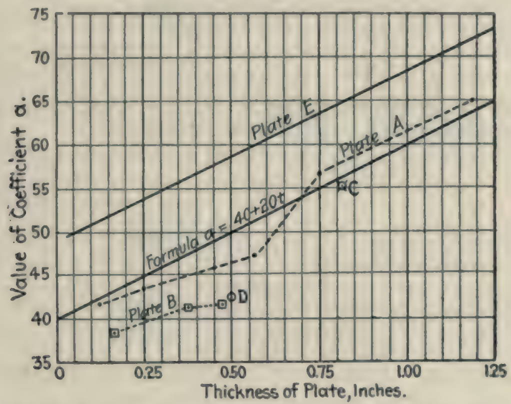

FIG. 86.—VALUES OF a, FROM BLECHYNDEN'S EXPERIMENTS.

surface is not equally effective, part of it being short-circuited and in contact with eddies of comparatively cool gas.

Durston's Experiments on the Transmission of Heat through Plates.*—A. J. Durston describes some experiments made to determine the temperature of the hot side of a plate, exposed to hot gases, when the other side was covered with boiling water. The temperature was determined by the melting of fusible solders on the hot side of the plate. The following is a summary of the results:

1. Temperature of hot side of a clean plate exposed to gases at about 1500° F. . . . . about 240° F.
2. Same with a layer of grease $\frac{1}{32}$ in. thick over inside of vessel. . " 330°
3. Temperature at the centre of thickness of a plate . . . . between 290° and 336.°
4. Loss of efficiency of heating surface of boiler-tubes due to a thin coating of grease, 8 to 15 per cent; mean of several experiments, 11%.
5. Temperature of hot side of plates where boiling water in an open vessel under various conditions; a flanged dish 2 ft. diameter, $2\frac{1}{4}$ in. deep, $\frac{3}{8}$ in. thick:

* Trans. Inst. Naval Architects, 1893, also Donkin, "Heat Efficiency of Steam-boilers," p. 157.

	Temperature of Fire.	Temp. Hot Side of Plate.
Clean fresh water	2200°	280°
Mineral oil gradually added up to 5%	2300°	310°
Fresh water with $2\frac{1}{2}$% of paraffine	2100°	330°
Fresh water with $2\frac{1}{2}$% of methylated spirits	2500°	300°
A greasy deposit $\frac{1}{16}$ in. thick on the plate	2500°	about 550°
Other experiments with greasy deposits showed that the temperature varied greatly, depending on the nature and thickness of the deposit.		

6. Temperature of plates when boiling water in a closed vessel at a higher temperature than 212°; using clean water:

	Temp. Hot Side of Plate.	Temp. of Water.	Difference.
Over Bunsen burner	430°	363°	67°
Over blast forge, full blast	430°	344.5°	85.5°
7. Same, bottom of vessel coated with grease:			
Over forge-fire, grease 1/16 in. thick	510°	359°	151°
Over grease drier, or earthier	550°	351°	199°
Over and spreading the grease up the sides of the vessel	617°	80°	537°

8. Experiments to determine whether at higher steam pressures there is any marked addition to the excess of temperature of the hot side of the plate over that of the water showed no marked addition.

Effect of Circulation upon Economy.—In the above discussions concerning the several conditions which have an influence on the economy of a steam-boiler, nothing has been said of the effect of circulation of the water. It is contended by some writers that some boilers have a more active circulation of water than others, and that the transmission of heat, and therefore the efficiency of the heating surface, is greater the more rapid the circulation; but the author is not aware that this view is supported by the results of trials of steam-boilers. It is well known that a steam-radiator used for heating air transmits a vastly greater quantity of heat when the air is blown upon by it by a fan than when the air surrounding it is comparatively still—that is, merely moving upward at the velocity of the ascending column of heated air; also that a coil used for heating water is more effective when the water is given a rapid motion; the reason being that the rapid circulation of the air, or water, constantly removes from the heating surface the heated body and replaces it with a cool one, and the rate of transmission increases approximately

as the square of the difference of temperature on the inside and outside of the coil. The case is entirely different with steam-boilers. There is in all modern forms of boilers a rapidity of circulation sufficient to keep all the water surrounding the heating surfaces at nearly the same temperature of the steam, so that the difference of temperature on the two sides of a square foot of heating surface, with uniform furnace conditions, remains practically constant.

If there should be a film of steam, or a "steam-pocket," on one side of the surface, keeping the water from wetting it, the transmission of heat would be greatly diminished, so that there might even be danger of the plate becoming overheated; but this condition is unlikely to happen in boilers of any of the ordinary forms.

Upon this subject Charles Whiting Baker writes as follows:*

So far as the transmission of heat upon the boiler in making steam is concerned, the circulation of the water in boilers is of a good deal less consequence than has sometimes been claimed. I do not mean by this that it is not worth while to make proper provision for circulation. There are possibly some boilers worked with forced draft, such as the tube-plates of marine boilers, where it is so difficult for the steam-bubbles to get away fast enough that we have a mass of foam instead of water in contact with the plate. Under such conditions, of course, the plate is bound to be heated; but I know of no evidence that this is any other than a rare occurrence, even in boilers which are pushed most severely. . . . Let it be understood that I am referring to circulation only as affecting the transfer of heat and the consequent economy and capacity of the boiler. Good circulation is desirable to prevent unequal heating of the boiler and consequent straining, and it may be desirable in preventing deposits of scale and mud in places where they are least desirable; but that it has any appreciable effect on economy and capacity is not proved and probably cannot be.

Dr. Charles E. Emery in a discussion on "Tubulous Boilers," says:†

Our original conception of "convection" or "circulation" is exemplified in all boilers of ordinary type. Multiplication and various arrangements of the tubes make this circulation more and more active without changing its nature until, with the very small tubes referred to by Mr. Thornycroft, the action becomes violent and somewhat intermittent, like a geyser.

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* Trans. A. S. M. E., vol. xix, p. 579.
† Journal Am. Soc. of Naval Engineers, vol. ii. No. 3.

We then have this progression: a boiler in which the circulation is like that in a kettle, with steam and water rising at the centre and water descending at the sides, will operate satisfactorily; so, also, special and sectional boilers provided with water up-takes and down-takes, from the heating surface to a separate drum, will circulate on the same principles and operate satisfactorily. Curiously, this will be the case whether the up-takes be large or considerably contracted. We know that vertical boilers will operate well when there is a large space around the tubes for circulation; but the naval launch boilers and Mr. Manning's modification of the same, where the shell is brought in close to the tubes till it acts like a corset to prevent free circulation, also operates well. So, also, a locomotive boiler, with plenty of room around the tubes, operates well, and it also operates well when there is very little room around the tubes; the fact being that, with a large area of down-take, a large quantity of water is moved at a slow velocity, while with less area a less quantity of water is moved, but at a higher velocity, produced by a greater head, due to the fact that less water is mixed with the steam during its upward movement and the density of the column is less. The extreme of this progression is a tube so long and narrow that, with solid water fed into the bottom, the greater part of the tube will be a mass of foam, and mixed steam and water be discharged continuously or spasmodically at the upper end. It is, moreover, found that the steam and water of which the foam is composed can be separated in smaller space than is required with less vigorous ebullition. In other words, contrary to our old ideas of large steam-space, large disengaging surface and quiet ebullition to prevent foaming, we can apparently obtain as good results in a boiler composed of long, narrow tubes, each of which foams vigorously, perhaps spasmodically, in true geyser style, though not foaming in the sense ordinarily understood where water is carried to the engine.

In ordinary boilers the steam passes upward and bubbles through the water at the disengaging surface, which plan operates satisfactorily, but with the geyser type of boilers there are differences of opinion whether or not it is best to discharge the upward current of mixed steam and water under the surface of the water in the drum or entirely above it. Mr. Thornycroft advocates the latter, and this system is adopted with modifications in the Ward and Belleville boilers.

A gentleman discussing Mr. Thornycroft's paper claims, however, that it is better to discharge the water and steam from small tubes below the water-level in the separating-drum. It may still be considered doubtful which system will carry least water to the steam-pipe. In the end it will probably be found that each mode of operation is adapted to a particular set of conditions.

Efficiency does not Depend on the Type of Boiler.—It will be shown in the chapter on Results of Trials of Steam-boilers that boilers

of a great variety of types have all given practically identical economic results, approaching the maximum possible results when the operating conditions are favorable, but the following extract from the same discussion of Dr. Emery, quoted above, may be given here:

The economy of a boiler does not depend upon its type, or the particular way the water is circulated, but upon the simple principle that when there is proper circulation of both the water and the products of combustion, the economic result is a function of the average quantity of combustible burned per square foot of heating surface. It is important that there be proper circulation, not only of the water, but of the products of combustion. Many special boilers have large chambers and curious-shaped passages, so arranged that the products of combustion do not necessarily pass over all portions of the heating surface; the current takes the lines of least resistance, and while the surface actually passed over is very efficient, the average efficiency is low.

It being settled that the economy of the different types of boiler is based on the same law, the efficiency is frequently very low, which is due generally to the improper distribution of the heated gases over the heating surfaces, whereby a large portion of the gases can take a short circuit to the stack. This difficulty is easily overcome in ordinary boilers by reducing the cross-area for draft, so that the whole heating surface becomes efficient, which can be done if the products of combustion either pass through fire-tubes or between water-tubes. With tubulous boilers it is more difficult, as all possibility of direct access must be given up if the tubes are massed closely together in a flue. In the writer's opinion, the best form of boiler for reasonable rates of combustion is one with inclined tubes connected by up-takes and down-takes to a chamber or drum above, as in many sectional boilers.

Comparison of Lancashire and Multitubular Boilers.—Chas. Erith, in *Engineering,* Feb. 4, 1913, gives the following dimensions of a Lancashire and of a horizontal return tubular boiler, each of which, he says, is equally capable of the rating of 300 American boiler horsepower or 10,350 lbs. hourly equivalent evaporation from and at 212° F.

	Shell Dimensions.	Heating Surface.	Gas Flues, Number and Size.	Furnace Width.
Multitubular....	20×7 ft.	3056 sq.ft.	192, 3 in.×20 ft.	7 ft. 1 in.
Lancashire......	30×8 ft.	1000	2, 39 in.×30 ft.	6 ft. 1 in.

"With correct combustion and good coal," says Mr. Erith, "either boiler should give say 72% efficiency without, or say 78% with, an economizer." His conclusion is that the Lancashire boiler with only

1000 sq. ft. heating surface, is the equal, both in capacity and efficiency, of a multitubular boiler of 3056 sq. ft. heating surface. The fact is that with good coal and "correct combustion" (that is combustion in a fire brick chamber and with the air supply controlled by gas analysis) and proper protection against air leaks and radiation, the multitubular boiler could be driven to 2½ times its rating, or 750 H.P. without the efficiency falling below 72%. It would then be driven at the rate of $(750 \times 34.5) \div 3056 = 8.47$ lbs. from and at 212° per sq. ft. of heating surface, as compared with 10.35 lbs. for the Lancashire when operating at only 300 H.P. There is no reason to believe that a square foot of surface of the multitubular boiler is any less efficient in transmission of heat than a square foot of Lancashire boiler, while the latter has the disadvantage of greatly increased radiating surface, greater cost of boiler and setting and of space occupied, and narrower furnace width. These reasons have prevented the introduction of the Lancashire boiler in the United States, and will in time no doubt cause its disappearance in England.

It is interesting to note that the total area of the two 39-in. gas flues of the Lancashire boiler is 16.6 sq. ft. while that of the 192 tubes of the multitubular boiler is only 8.1 sq. ft. If both boilers were driven at the same rate, using the same amount of coal and the same air supply the velocity of the gases in the tubular boiler would be more than double the velocity in the Lancashire, and if the American boiler were driven to 750 H.P. the velocity would be more than five times as great. The fact that the two boilers give about the same efficiency is strong indication that, contrary to the opinions of some recent writers, the velocity of the gases has little if anything to do with boiler efficiency.

Effect of Velocity of Gases on Efficiency.—The velocity of the gases varies not only with the weight of coal burned and inversely as the area of the gas passage, but also with the weight of gas per pound of coal and with the volume in cubic feet per pound of gas, which varies with the temperature from the fire-box to the chimney flue. To eliminate some of these variables let us assume that the weight of gas is 20 lbs. per lb. of coal burned and that the velocity is measured at a point in the gas passage where the temperature is about 1000° F. and where its volume is 36 cu. ft. per lb. Then $20 \times 36 \div 3600 = 0.2$ cu. ft. of gas per second per pound of coal burned per hour. If $F =$ lbs. coal per hour and $A =$ area of gas passage in sq. ft. then $0.2F/A =$ velocity of the gas in feet per second, which gives us a rough approximation by which we may estimate the relative velocity of the gases in different boilers. For the purpose of comparison we may take the Lancashire and multitubular boilers above referred to, the former evaporating 10,350 and the latter $750 \times 34.5 = 25{,}875$ lbs. water from and at 212° per hour, and each evaporating 10 lbs. water per lb. of coal. We may also take the Galloway (a modified Lancashire) boiler tested at the Centennial Exhibition in 1876 for maximum economy with semi-bituminous coal, and two

tests of a locomotive reported by Prof. W. F. M. Goss, in Bulletin 402 of the U. S. Geological Survey, 1909, in the latter case using combustible instead of coal burned, on account of the loss of cinders in the smoke-box and stack. The data are as follows:

Boiler.	H.P. Developed.	Fuel Burned per Hr., Lbs.	Area of Gas Passage, Sq.ft.	Velocity of Gas, Ft. per Sec.	Efficiency.	Equivalent Evaporation per Sq.ft. H.S. per Hr., Lbs.
Galloway.....	103	284	11.9	4.8	74.5	3.20
Lancashire....	300	1035	16.6	12.5	72	10.35
Multitubular..	750	2588	8.1	64	72	8.47
Locomotive...	181	504	3.4	28	74.1	5.12
" ...	469	1569	3.4	92	62.7	13.30

The first of the two locomotive tests and the test of the Galloway boiler both show high efficiency for hand firing, but in the former the velocity of gases is 5.8 times that in the latter. The second of the locomotive tests shows a velocity of gas 19 times that in the Galloway boiler, but the efficiency was low, on account of the high rate of driving, and probably also on account of imperfect combustion, as the unaccounted for loss in the heat balance was 10.6 per cent. It will be difficult to derive from the figures in the above table any confirmation of the belief that velocity of the gases is an important factor of efficiency.

APPENDIX TO CHAPTER IX.

NOTE 1, p. 288.—The integration may be done as follows: Let $(T - t) = x$, $d(T - t) = dT = dx$, t being a constant.

$$\frac{dT}{(T-t)^2} = x^{-2}dx; \qquad \int_{T_2}^{T_1} x^{-2}dx = -\frac{1}{T_1 - t} + \frac{1}{T_2 - t};$$

$$\frac{S}{acw} = \frac{1}{T_2 - t} - \frac{1}{T_1 - t}.$$

After finding this formula Rankine proceeds as follows ("Steam-engine," p. 265):

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1 - t} = \frac{S(T_1 - t)}{S(T_1 - t) + cwa}.$$

Let H = expenditure of heat in raising the temperature of the hot gas above that of the water. Then $T_1 - t = H \div cw$, whence

$$\frac{T_1 - T_2}{T_1 - t} = \frac{SH/cw}{SH/cw + acw} = \frac{S}{S + ac^2w^2/H}.$$

Again, p. 293, Rankine says:

"Let E = theoretical evaporative power and E_1 = available evaporative power of 1 lb. fuel, in a boiler in which the area of heating surface is S. Then

$$\frac{E_1}{E} = B \cdot \frac{S}{S + ac^2w^2/H},$$

where B is a fractional multiplier to allow for various losses of heat, whose value is to be found by experiment. Now $c^2\ w^2$ is proportional to $F^2\ V_0{}^2$, where F = lbs. of fuel burned in the furnace in a given time, and V_0 is the volume at 32° of the air supplied per lb. of fuel. Also $H \propto F \times$ a constant. Hence it may be expected that the efficiency of a furnace will be expressed to an approximate degree of accuracy by

$$\frac{E_1}{E} = \frac{BS}{S + AF},$$

where A is a constant to be found empirically, and is probably proportional approximately to the square of the quantity of air per lb. of fuel."

This is Rankine's formula for efficiency as a function of the heating surface, which is often quoted, but it is not generally known that his so-called "efficiency," $\frac{E_1}{E} = \frac{T_1 - T_2}{T_1 - t}$, is quite different from the efficiency as defined by Hale and others, viz., $\frac{E_a'}{E_p} = \frac{T_1 - T_2}{T_1}$, which corresponds to what is commonly known as "the efficiency of a boiler." Suppose in a given case $T_1 = 2400$, $T_2 = 600$, $t = 300$. Then $\frac{E_a'}{E_p} = \frac{T_1 - T_2}{T} = \frac{1800}{2400} = 75$ per cent efficiency, while Rankine's formula would give $1800 \div 2100 = 85.7$ per cent. The coefficients A and B are given by Rankine as follows:

	B	A
Boiler Class I. The convection taking place in the best manner, either by introducing the water at the coolest part of the boiler and making it travel gradually to the hottest, or by heating the feed-water in a set of tubes in the up-take; the draft produced by a chimney	1	0.5
Boiler Class II. Ordinary convection, chimney draft.	$\frac{11}{12}$	0.5
Boiler Class III. Best convection, forced draft.	1	0.3
Boiler Class IV. Ordinary convection, forced draft.	$\frac{19}{20}$	0.3

No satisfactory reason is given for the adoption of these values. These coefficients of Rankine are quite different from the A and B of the formulæ (8) and (9) on page 289.

"True Efficiency."—In the reports of the tests of the U. S. Geological Survey at St. Louis in 1904 (see Bulletin 325, U. S. G. S., 1907, also Bulletin 18 of the U. S. Bureau of Mines, 1912) the term

"true efficiency" is used to denote the ratio $(T_1-T_2)\div(T_1-t)$, in which T_1 is the furnace temperature, T_2 the temperature of the chimney gases and t the temperature of the water in the boiler. The relation of this ratio to that of the one commonly accepted, $(T_1-T_2)\div T_1$, is $T_1\div(T_1-t)$, which is a constant, independent of T_2 when T_1 and t are constant. The introduction of this new term therefore serves no useful purpose. For a detailed criticism of it and of the conclusions of the writers of these reports concerning boiler performance, see the author's article on Steam Boiler Efficiencies in *Industrial Engineering,* Oct. 1912, p. 145.

NOTE 2, p. 288.—To obtain formula (5) we have

$$\frac{E_a'}{E_p}=\frac{T_1-T_2}{T_1}. \quad . \quad . \quad (1) \qquad \frac{S}{cwa}=\frac{T_1-T_2}{(T_2-t)(T_1-t)}. \quad . \quad . \quad (4)$$

$$T_1E_a'=T_1E_p-T_2E_p; \qquad T_2=T_1\,\frac{(E_p-E_a')}{E_p}.$$

Substituting this value of T_2 in (4),

$$\frac{S}{cwa}=\frac{T_1-\dfrac{T_1E_p-T_1E_a'}{E_p}}{(T_1-t)\left(\dfrac{T_1E_p-TE_a'}{E_p}-t\right)}=\frac{T_1E_a'}{(T_1-t)[(T_1-t)E_p-T_1E_a']}$$

$$=\frac{T_1E_a'}{(T_1-t)^2E_p-(T_1-t)T_1E_a'}.$$

Put $\dfrac{acw}{S}=P$, and $(T_1-t)=T_3$.

Then $\quad P=\dfrac{T_3{}^2E_p-T_3T_1E_a'}{T_1E_a'}; \quad (PT_1+T_3T_1)E_a'=T_3{}^2E_p;$

$$\frac{E_a'}{E_p}=\frac{T_3{}^2}{PT_1+T_3T_1}=\frac{T_3{}^2\div T_1}{T_3+P}=\frac{(T_1-t)^2\div T_1}{(T_1-t)+\dfrac{acw}{S}}. \quad . \quad . \quad (5)$$

NOTE 3, p. 289.—*Is the rate of transmission directly proportional to the temperature difference?* Equations (3) to (16) are based on the hypothesis (according to Rankine) that the rate of transmission q varies as the square of $(T-t)$, or that $q=\dfrac{(T-t)^2}{a}$, a being a constant. This hypothesis has been objected to by some writers, who hold that the transmission varies directly as the temperature difference instead of as the square, or $q=\dfrac{(T-t)}{b}$, in which b is a constant. Let us test the validity of this formula.

Referring to eq. (3), we have

$$\frac{S}{cw} = b\int_{T_2}^{T} \frac{dT}{T-t}.$$

Integrating, $$\frac{S}{cwb} = \text{hyp. log. } \frac{T_1-t}{T_2-t}.$$

From eq. (1), we obtain

$$T_2 = \left(1-\frac{E_a'}{E_p}\right)T_1, \quad \text{and} \quad w = fF = \frac{W'}{E_a'}f;$$

whence $$\frac{SE_a'}{cW'bf} = \text{hyp. log. } \frac{T_1-t}{\left(1-\frac{E_a'}{E_p}\right)T_1-t}$$

$$b = \frac{S}{W'}\frac{E_a'}{fc}\,\frac{1}{\text{hyp. log. } \dfrac{(T_1-t)}{\left(1-\frac{E_a'}{E_p}\right)T_1-t}}.$$

If all the quantities in the second member of this equation are known, b can be found, but if b is given and E_a' is required, the latter cannot be found by direct algebraic process.

Referring to the diagram Fig. 77, page 299, the line corresponding to $f=20$, $t=300$, $R=0.1$ corresponds nearly to the actual maximum results obtained in good boiler practice, and it may safely be assumed that the line $R=0$ in Fig. 78 closely approximates the highest possible results with $f=20$, if the radiation loss were entirely suppressed. This line gives us values for E_a'/E_p which may be substituted in the above formula, in order to obtain the value of b.

From the table on page 297 we find that with $K = 14{,}800$, $t = 300$, $T_1 = 3083$, $f = 20$, $c = 0.24$, $a = 200$, $R = 0$, the values of E_a' and E_a'/E_p and the corresponding values of b are as follows:

$\frac{W'}{S} =$	1	2	3	4	6	8
$E_a' =$	13.422	13.077	12.732	12.387	11.698	11.008
$E_a'/E_p =$	88.01	85.74	83.48	81.22	76.70	72.18
$b =$	0.759	0.455	0.340	0.281	0.214	0.178
$1 \div b =$	1.318	2.198	2.941	3.589	4.673	5.618

It thus appears that b is not a constant but a variable, varying as some decreasing function of W'/S. The reciprocal of b, or $1 \div b$, is also a decreasing function of W/S. We therefore conclude that the assumption that $q = (T - t) \div b$, or that the rate of transmission varies directly as the difference of temperature, is incorrect.

F. Kingsley (*Eng. Record,* Aug. 29, 1908) discusses at length the question whether the rate of heat transmission varies directly as the difference of temperatures or as the square of that difference. He shows mathematically that if the transmission varies directly as the temperature difference, then in a boiler divided into four sections of equal heating surface the ratios between the evaporation in each two adjoining sections would be respectively 0.50, 0.50, 0.50; while if the transmission varies as the square of the temperature difference, the ratios would be 0.50, 0.60, 0.667. He calculates these ratios for two series of tests used by M. Havrez (Proc. Inst. Civ. Engrs., vol.39) to demonstrate that the heat transfer varied directly as the temperature difference, and three series of tests cited by Prof. Perry in his book on steam engines to substantiate his theory based on the same assumption. The average figures for the five series of tests gives for the three successive ratios 0.504, 0.589, 0.670, which are remarkably close to the figures corresponding to the assumption that the transmission varies as the square of the temperature difference.

NOTE 4, p. 290.—*Interpretation of formula* (7), $E_a' = BE_p - A\frac{W'}{S}$. —If $\frac{W'}{S} = 0$, $E_a' = BE_p$. That is, the evaporation per lb. of fuel will be the greatest when the evaporation per sq. ft. of heating surface is least. (This will not be true when radiation is considered.)

If $A\frac{W'}{S} = BE_p$, or $\frac{W'}{S} = \frac{BE_p}{A}$ $E_a' = 0$. This seems to be a paradox, for can there be any rate of evaporation at which the economy, or the evaporation per lb. of fuel, will be 0? Substituting for W' its value FE_a', we have $E_a' = BE_p - \frac{AE_a'F}{S}$; and for $E_a' = 0$, $BE_p = \frac{AF \times 0}{S}$, which, if BE_p, A, and S are finite quantities, can only be true if $F = \infty$. That is, when $W'/S = BE_p/A$, a finite quantity, the fuel consumption is infinite, and any actual evaporation, as W, divided by infinite $F = 0$.

The conclusion is that a rate of evaporation per sq. ft. of heating surface equivalent to $W'/S = BE_p/A$ can never be reached until the fuel consumption F is so great that the final temperature of the gases T_2 equals their initial temperature T_1, which can occur only with no transmission of heat through the heating surface, or with an infinite fuel consumption.

NOTE 5, p. 291.—*Development of equation* (11).

$$E_a = BE_p - A\left(\frac{W}{S} + R\right) - \frac{RSE_a}{W};$$

$$E_a + \frac{RS}{W}E_a = BE_p - A\left(\frac{W}{S} + R\right);$$

$$E_a = \frac{BE_p}{1+\dfrac{RS}{W}} - \frac{A\left(\dfrac{W}{S}+R\right)}{1+\dfrac{RS}{W}}.$$

The last term equals $A\dfrac{W}{S}$; therefore $E_a = \dfrac{BE_p}{1+\dfrac{RS}{W}} - A\dfrac{W}{S}$.

NOTE 6, p. 303.—*Variable Specific Heats.*—From a table of the thermal capacity of various gases at different temperatures, given in Damour's Industrial Furnaces (M. E. Pocket-book, p. 537), the following figures for the mean specific heat (between 32° F. and the temperatures named) of a furnace gas consisting of $12CO_2$, 8O, 80N (corresponding to 23 lbs. of gas per lb. of carbon), have been computed:

3000° F.	0.283	2000° F.	0.266	1000° F.	0.249
2800	0.279	1800	0.262	800	0.247
2600	0.276	1600	0.258	600	0.246
2400	0.273	1400	0.254	400	0.245
2200	0.273	1200	0.251		

Assuming 0.275 as the specific heat of the gas in a furnace, the computed elevation of temperature above that of the atmosphere, with 23 lbs. of gas per lb. of fuel, and a heating value of 14,800 B.T.U. per lb., is $14,800 \div (0.275 \times 23) = 2340°$. As a temperature of 3000°, as measured by pyrometers, is often obtained in boiler furnaces, it is probable that the above figures for specific heats at the higher temperatures are too high.

The temperatures T_2 and the efficiencies found for the boiler of 20 sections have been recalculated on the basis of variable specific heat, with $f = 20$, and the results are given below, compared with those found in the original computation with c taken at 0.24:

Section No.	1	2	3	4	5	6	7
Value of C	0.268	0.257	0.251	0.250	0.249	0.248	0.247
Temperature T_2	1800	1456	1286	1120	1002	913	844
Temperature original	2045	1571	1300	1125	1001	910	844
Efficiency, per cent	32.61	45.54	53.80	59.76	64.01	67.21	69.69
Efficiency, original	33.61	49.00	57.79	63.47	67.50	70.46	72.60

Section No.	8	10	12	14	16	18	20
Temperature T_2	789	714	653	608	573	545	522
Temperature original	787	703	645	600	566	539	517
Efficiency, per cent	71.66	74.63	76.79	78.40	79.64	80.63	81.44
Efficiency, original	74.45	77.37	79.06	80.52	81.62	82.50	83.22

The difference between the revised and the original results are not of sufficient importance to warrant the adoption of variable specific heats in computations of boiler efficiency, especially as their value at the different temperatures is not well established.

CHAPTER X.

TYPES OF STEAM-BOILERS.

Evolution of Different Forms of Boiler.—The first stage in the development of steam-boiler construction beyond the plain cylinder boiler was the recognition of the fact that it is defective in providing too little heating surface for its first cost, for the ground space it occupies, and for the expense of its setting. Only about one-half of its whole shell surface is available as heating surface; the remainder serves only to hold the steam. Increase of its diameter involves increase of the thickness of its shell, and hence greater cost per square foot of heating surface, as well as increase of area occupied. Increase of its length involves equal increase of ground space and of cost of

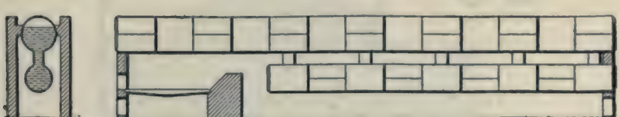

FIG. 87.—DOUBLE-CYLINDER BOILER.

setting, besides increasing the difficulty of suspending it in such a manner as to avoid dangerous strains. Some radical change of form must then be found. In the United States the first departure from the plain cylinder boiler was made in two different directions in different localities. In blast-furnaces additional heating surface was provided by hanging one cylindrical shell below another, joining the two by short legs. Such a construction is shown in Fig. 87. The upper cylinder was generally made of larger diameter than the lower. On the Ohio and Mississippi rivers, steamboat boilers were made by enlarging the diameter of the cylinder and by putting two flues inside of it, the gases passing under the boiler and then returning through the two flues to the chimney, which was placed at the front of the boiler. This form is shown in Fig. 88. This boiler came into universal use on the western rivers, and into quite general use in the cities and towns located along these rivers. Until about the year 1880 scarcely

any other kind of boiler was in use in the large iron-mills and in the mines in and around Pittsburg, such is the force of local custom and prejudice. Now, however, it is rapidly being displaced on land by

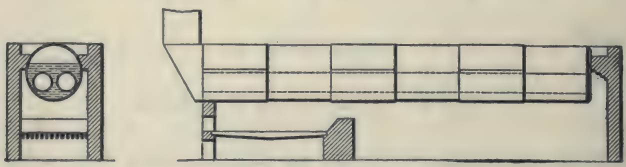

FIG. 88.—TWO-FLUE BOILER.

modern water-tube boilers, although it still holds its own on the steamboats.

Evolution of the Steam-boiler in France and England.—In France the development from the plain cylinder boiler took a form similar

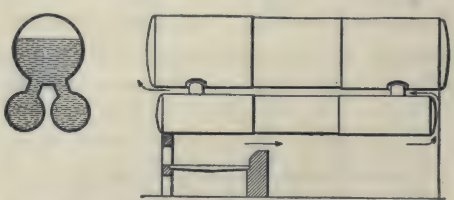

FIG. 89.—THE "ELEPHANT" BOILER.

to that of the double-cylinder boiler, but with two lower cylinders hanging from the upper one, as shown in Fig. 89. This boiler is commonly called the "elephant" boiler.

In England the plain cylinder boiler developed into the Cornish boiler, in which the cylinder is made of larger diameter and a large

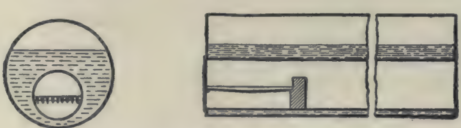

FIG. 90.—THE CORNISH BOILER.

central flue is built into it, in one end of which the grate is placed. This boiler is shown in Fig. 90. A modification of the Cornish boiler is the Lancashire, containing two internal furnaces and flues, shown in Fig. 91. Another modification is the Galloway boiler, in which the two internal furnaces lead into one large flue, oblong in cross-section, crossed by a number of conical-shaped water-tubes,

which circulate the water from the space below to the space above the flue, baffle the course of the gases through the flue, and provide increased heating surface, as is shown in Fig. 92. The Lancashire boiler is now often built with Galloway tubes crossing each of its

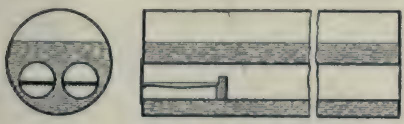

FIG. 91.—THE LANCASHIRE BOILER.

FIG. 92.—THE GALLOWAY BOILER.

flues, as shown in Fig. 93. This cut also shows, in cross-section, the common form of setting of Galloway and Lancashire boilers. The gases first pass through the internal flues, then return in the two external flues along each side, and finally pass through the

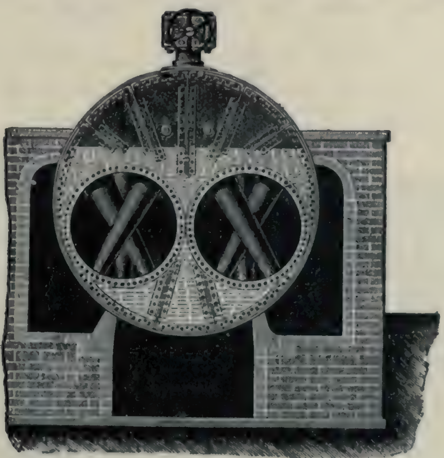

FIG. 93.—LANCASHIRE BOILER WITH GALLOWAY TUBES.

single flue under the shell of the boiler. Sometimes the gases are made to pass to the front under one side of the shell and then return to the rear under the other side. All of the boilers above described are open, although to a smaller degree, to the same objection that has been raised against the plain cylinder boiler—that of providing too small an amount of heating surface for their cost and for the ground space occupied. The objection applies less to the Galloway than to the other forms.

The Horizontal Return Tubular Boiler.—The American two-flue externally fired boiler has developed through the stages of five and ten

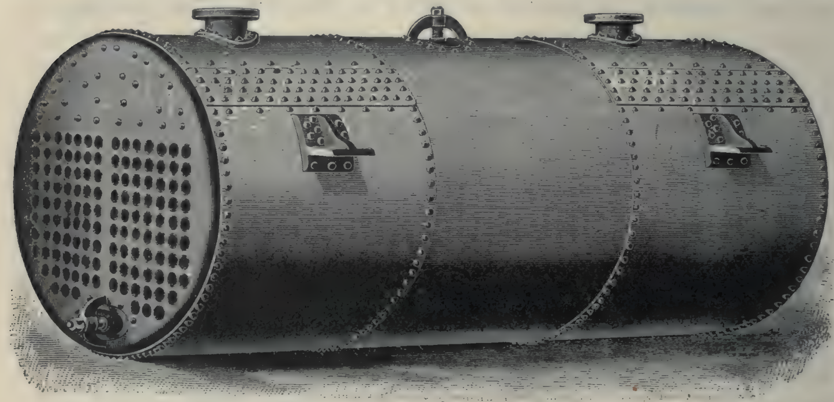

FIG. 94.—HORIZONTAL RETURN TUBULAR BOILER.

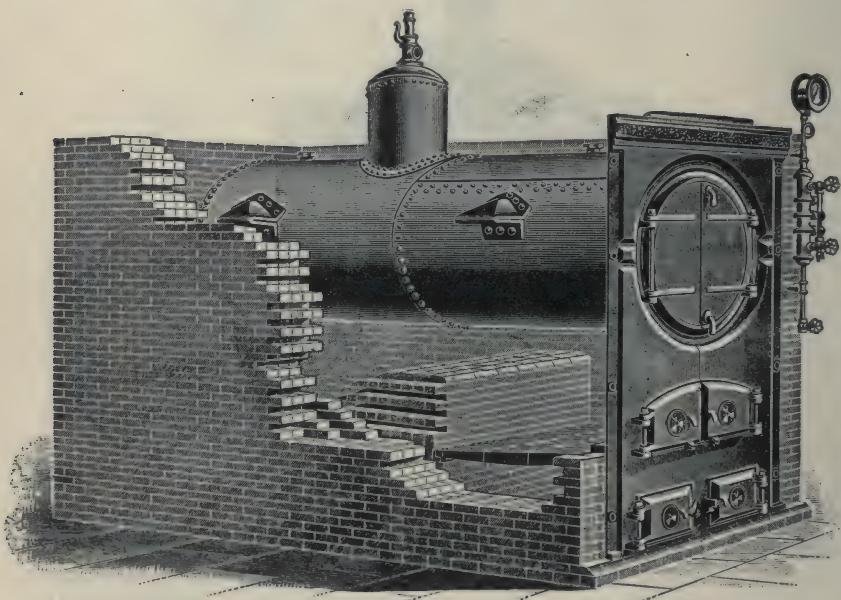

FIG. 95.—RETURN TUBULAR BOILER WITH SETTING.

flues into the modern American horizontal multitubular externally fired fire-tube boiler, containing often 100 tubes or more, of 3 or 4 inches diameter, shown in Figs. 94 and 95.

Fig. 94 shows the most recent form of this boiler with butt and strap riveting on the longitudinal seams, adapted for high pressures. Fig. 95 shows an earlier form for moderate pressures, with the common style of setting. The steam-drum shown on this boiler is now generally abandoned, being considered a useless and even dangerous appendage.

In the return tubular boiler the objection of insufficient heating surface in proportion to space occupied, is removed to a greater extent than in any other boiler with the exception of some forms of water-tube boilers, and in regard to cost it is about the cheapest of all boilers for a given extent of heating surface. It is probably in more general use in the United States than any other form of boiler. As already stated, it is practically not used at all in England, where there is a strong prejudice against it and in favor of the internally fired Lancashire and Galloway boilers. Its extensive introduction into this country is no doubt due to its low first cost. When well made of good material, when the water used is reasonably free from scale-forming substances, and when it is carefully handled and frequently inspected, it may give satisfaction for long periods of time, and so justify the favor in which it is held. This type of boiler is, however, very liable to explosion, and many lives are lost by its use every year. The shell of the horizontal tubular boiler being directly exposed to the fire, it is especially liable to be burned or weakened when there are deposits of scale or grease upon it. The circular rivet-seams, and the double thickness of plates at the seams being exposed to the fire, are also elements of weakness.

As to economy of fuel, the horizontal tubular boiler is subject to the same rules as all other boilers. Maximum economy may be obtained from it if the furnace is of a kind which will burn the coal thoroughly, if the extent of heating surface is sufficient for the amount of coal burned, and if the passages through the flues are so restricted in area that the gases traverse the upper and lower rows with approximately the same velocity. It is in this latter condition that the horizontal tubular boiler is usually defective. There is a tendency of the hot gases to pass through the upper rows of tubes instead of through all the tubes alike. This is easily proved by inserting a stick of wood, say $1 \times 2 \times 10$ inches, set edgewise, in the end of each tube in a vertical row, nearest the chimney, and leaving it there for say half an hour. The sticks in the upper tubes will usually be found to be burned up, while those in the lower tubes will

be only charred. This short-circuiting of the gases may be avoided by partially restricting the flow through the upper tubes, but it would require considerable experimenting, by placing thermometers in several of the tubes, and varying the relative obstruction to the current in the different tubes until all of the thermometers showed the same temperature. Actual tests of tubular boilers show results varying all the way from about $11\frac{1}{2}$ lbs. of water from and at 212° per lb. of combustible, down to 8 pounds, or about 30 per cent, with no difference in the coal, the rate of combustion or the character of the firing to explain the variation. It is probable that in such cases some of the low figures are due to short circuiting of the gases, which might be avoided by properly retarding the flow through the upper tubes.

The Vertical Tubular Boiler.—If a horizontal tubular boiler is filled with tubes, turned up on end and set over a furnace, it becomes

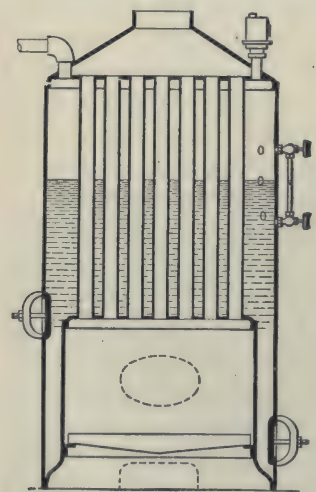

FIG. 96.—VERTICAL TUBULAR BOILER.

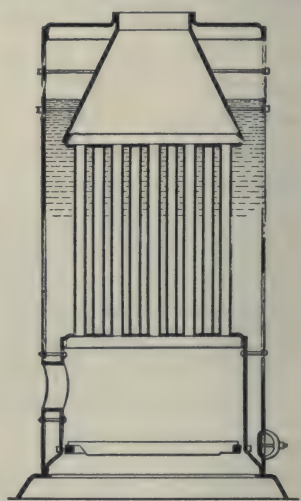

FIG. 97.—VERTICAL BOILER WITH SUBMERGED TUBES.

a vertical fire-tube boiler. It is more common, however, to build this type of boiler with an internal fire-box from 2 to 4 ft. in height. The annular space, 2 or 3 in. wide, between the fire-box and the shell, is known as the water-leg. The roof of the fire-box, a flat sheet into which the lower ends of the tubes are expanded, is called the crown-sheet, and the flat sheet on top of the boiler into which the upper ends of the tubes are expanded, is called the upper tube-sheet. The external appearance of such a boiler is shown in Figs. 96 and 97. The

crown-sheet is just below the hand-hole plate seen in the front of the shell some distance above the fire-door.

This boiler is the most commonly used type of boiler in the United States for small powers, say 5 to 40 H.P. It is also the most dangerous form, and the one which explodes oftener than any other. As commonly built, the water-level is carried a considerable distance below the upper ends of the tubes, which are therefore apt to be overheated and unduly expanded, bringing severe strains on both the upper tube-sheet and the crown-sheet. The crown-sheet is apt to accumulate a thick layer of mud and scale, which is liable to cause the sheet to crack, and this may lead to an explosion.

Increased safety with this type of boiler is obtained by so constructing it that the upper ends of these tubes are submerged, and by providing facilities for inspection and for the removal of scale from the crown-sheet.

The vertical tubular boiler is usually not economical of fuel, on account of its being designed with too small an amount of heating surface for the amount of coal burned in its fire-box, but it may be made as economical as any other boiler if properly designed and if driven at not too high a rate. The fire-box is usually too low to allow of complete combustion of the gases distilled from soft coal, even semi-bituminous, and the fire-tubes are too short to absorb the desired amount of heat from the hot gases. Recent designs are much better in these respects. Tubes are made as much as 18 or 20 ft. long, and fire-boxes as high as 8 ft. from the grate-bars to the crown-sheet have been built, with good results as to economy and smokelessness with semi-bituminous coal.

The Manning Boiler, Fig. 98, is a modification of the vertical tubular boiler, with structural features peculiar to itself. It is largely used in the New England States. An especial merit claimed for it is economy of ground space. A boiler which has given 180 boiler horsepower is set on a space 8 ft. in diameter. The difference in expansion and contraction between the tubes and the outer shell is taken up in the double-flanged head connecting the barrel of the boiler with the outside of the fire-box, and forming an expansion joint. By means of this head the fire-box is enlarged so as to give the desired proportion of area of heating surface to grate surface. The crown is of such height to form a large combustion-chamber.

The outer fire-box shell is carried well up above the head, and hand-holes are placed exactly on a line with the crown-sheet. The

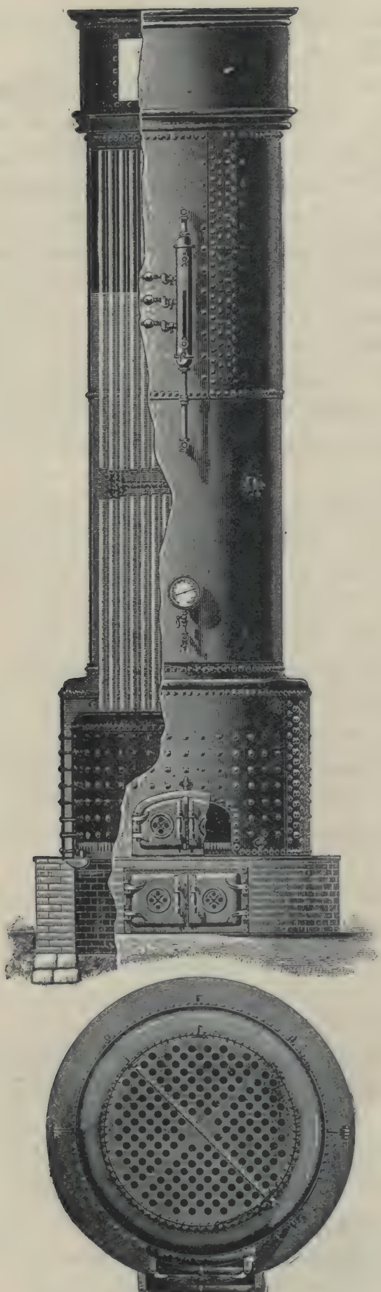

FIG. 98.—THE MANNING BOILER.

tubes are placed in straight rows, and at right angles to one another extend two cleaning-channels of ample size. A bent tube may therefore be inserted, and the crown-sheet thoroughly washed and cleaned. In the water-leg also are placed a number of hand-holes and a cleaning chain by means of which any sediment that may accumulate may be stirred up and removed.

The Locomotive Boiler.—The peculiar merits of the ordinary form of locomotive boiler, as used in locomotives, are its allowing to be crowded into a limited space a great extent of heating surface, with a large fire-box, its being self-contained, requiring no external furnace, and its great strength, admitting of working pressure of 200 lbs. and over. To obtain these advantages many other things have to be sacrificed. It is expensive, difficult to clean and to repair, is not durable, and must be driven with forced blast. It is also not economical when driven at the rate required for locomotive practice, the gases, leaving the smoke-stack at high temperatures, and at rapid rates of combustion a considerable amount of unburned coal is carried out of the stack or into the smoke-box.

Nevertheless, the locomotive type of boiler is not uncommon in stationary practice, its chief field

being for portable and semi-portable boilers. A common form of the type as used for stationary service is shown in Fig. 99.

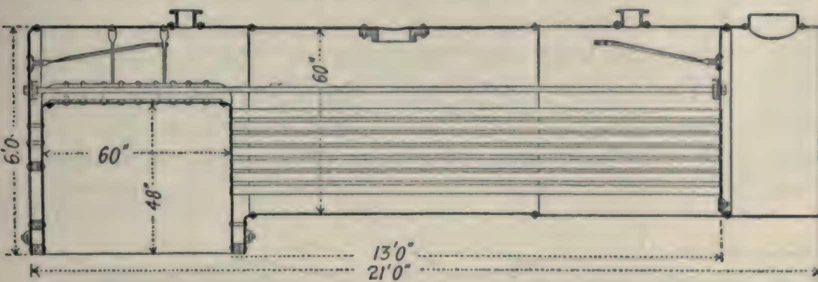

FIG. 99.—LOCOMOTIVE TYPE OF BOILER FOR STATIONARY SERVICE.

The "Scotch" Marine Boiler.—Boilers for marine purposes are built in a great variety of types, including modifications of the externally fired horizontal fire-tube and water-tube boilers, and of the various forms of internally fired boilers, such as the vertical tubular, the locomotive, the Lancashire, etc.

Take the Lancashire boiler, Fig. 91, with its cylindrical shell and two internal furnaces, and substitute for the two smoke-flues a combustion-chamber, a tube-sheet, and a great number of small tubes, and we have the first stage of development of the Lancashire into a modern marine boiler. The next stage is to increase the diameter of the boiler and shorten its length, extending the combustion-chamber upwards and putting the nest of tubes above the furnace-flues instead of in their rear, causing the tubes to return the gases toward the front of the boiler. This makes what is known as the "Scotch" boiler, so called because it was first built on the Clyde. Increase the diameter to 14 or 15 ft., and put in three or four corrugated furnaces, and we have the latest form of the boiler shown in Fig. 100.

This boiler is often made "double-ended," that is, it is increased in length and furnaces are placed in both ends, delivering their gases into a common combustion-chamber in the middle, from which the smoke-tubes extend to the chimney-flues at each end.

The Scotch boiler is now in almost universal use in large ocean-going merchant vessels, but in most large ships of war it has been displaced by the water-tube boiler.

The problem of designing a thoroughly satsfactory boiler for ocean service is one of great difficulty, and at best it offers but a choice of evils. In stationary service, on land, a boiler to be satisfactory

must have abundant grate surface, so that fires do not need to be forced; a large combustion-chamber, to help in the burning of the volatile gases, and plenty of heating surface to extract the heat from the gases. In marine service not one of these conditions can be provided, for space on board ship is too valuable. The problem may be stated thus: in a fire-room of so many square feet area and so many feet high construct boilers which shall have the greatest number of square feet of grate surface, and heating surface sufficient to absorb 65 or 70 per cent of the heating value of the coal when the coal is

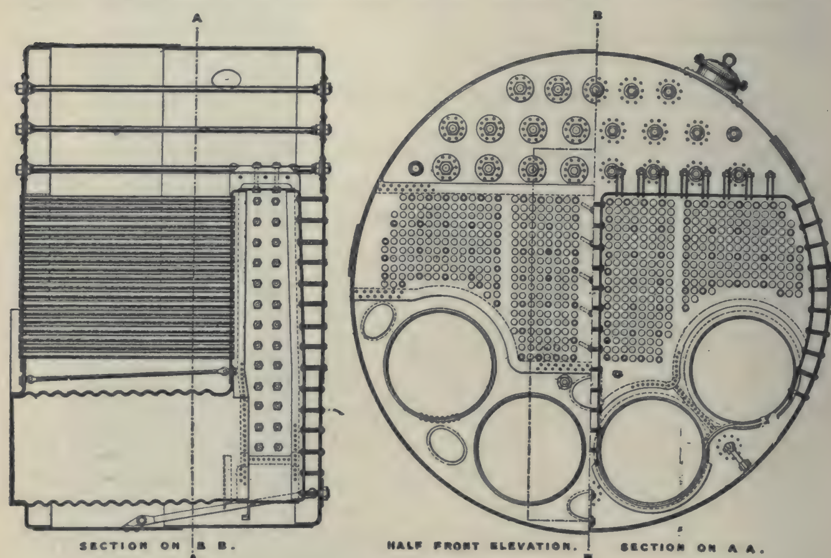

FIG. 100.—THE SCOTCH MARINE BOILER.

burned at the rate of 50 lbs. per hour per square foot of grate; at the same time the boiler must be strong, durable, easily cleaned and repaired, and must not weigh too much nor carry too much weight of water.

Until within recent years the Scotch boiler has been the one which most nearly filled these difficult requirements. It cannot fill them all, for it is heavy, both in metal and in water carried, is costly and difficult to repair.

Reason for the Survival of the Scotch Marine Boiler.—Rear Admiral G. W. Melville, U. S. N. says (*Eng'g Magazine,* Jan. 1912): "It seems to me that almost the only reasons for the continued use of the cylindrical boiler are the fact that marine people are so

thoroughly familiar with it and that nearly every shipyard has a boiler plant for turning out such boilers. In many cases the design of the machinery is left to the builders, who are thoroughly competent, but who naturally prefer to install a boiler which will give employment to the plant which they already have. This is easy to understand. What I cannot understand, however, is that owners and independent designers should continue to install such an unnecessary amount of dead weight when it might be replaced by lighter, safer, and more efficient boilers leaving a considerable increase in the cargo carrying capacity. . . . With the latest and best types of water-tube boilers we are able to secure not only power and lightness, but also economy."

The Water-tube Boiler.—In the water-tube steam-boiler the heating surface consists chiefly of tubes of small diameter, the water being contained in the inside of the tubes while the flame and gases of combustion are on the outside. The water-tube type of boiler forms a class broadly distinguished from the flue or tubular boiler, also called the fire-tube boiler, in which the water is contained in a large external shell and the gases pass through the flues or tubes. It is by no means a recent invention, since boilers of this type were made over a century ago, many forms of them being shown in standard treatises on boilers. It is only since the year 1870, however, that they have come into extensive use.

The great advantages of the water-tube type over all other forms of boiler, in point of safety from destructive explosions, ability to stand the highest pressures, perfection of circulation, compactness, economy of fuel, etc., were well understood many years ago, but it required a long course of development and experiment to discover what arrangement of parts and what mechanical details were necessary to combine these advantages with others not less essential, such as durability, and facility for cleaning and repair.

The form in which the water-tube boiler is now commonly made consists of a bank of tubes, usually 4 in. in diameter, and from 12 to 18 ft. long, inclined at an angle of about 15° from the horizontal, and surmounted by a horizontal water- and steam-drum, from 30 to 48 in. diameter, of about the same length as the tubes. The tubes are expanded into boxes or "headers," at each end, and these are connected to the drum overhead by circulating tubes or other connections. The water-level is carried about the middle of the drum, which on account of its comparatively large diameter offers a large disengaging surface which tends to insure the production of dry steam. The furnace be-

ing placed under the bank of tubes (or better, when soft coal is used in a fire-brick oven built in front of the boiler) the flame circulates amongst them, being properly guided by suitable passages so as to cause it to give up as much of its heat as possible before being allowed to escape into the chimney.

There are now several different makes of these boilers in the market, to all of which the above description will apply. They differ, however, in proportions of parts, in mechanical details, especially of the headers and their connection to the drum, in furnaces, in material, and in workmanship. The boiler type itself being good it still requires engineerng skill and good judgment to determine what size of boiler, what kind of furnace, and what arrangement of flues and chimney should be adopted to give the best results, considering the character of work to be done, and the kind of fuel to be used.

The great success of the water-tube type of boiler is chiefly shown by the fact that it is now being most extensively adopted by the concerns which use the largest amount of power, such as electric light and power stations, large sugar refineries, iron and steel works and the like, which require thousands of horse-power in one plant.

Early Forms of Water-tube Boilers.—Fitch & Voight's boiler, used by John Fitch in his steamboat on the Delaware River in 1787;

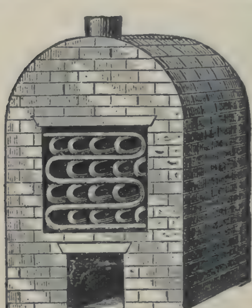

FIG. 101.—FITCH & VOIGHT, 1787.

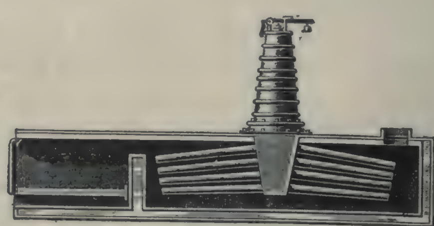

FIG. 102.—JOHN STEVENS, 1803.

Barlow's boiler, patented in France in 1793, and used by Robert Fulton in his steamboat experiments on the Seine, in France, in 1803, and John Stevens's boiler, used in his experimental twin-screw steamboat on the Hudson River in 1804, are three early forms. They are all described in Thurston's "Growth of the Steam Engine." Fitch's boiler was a "pipe-boiler," consisting of a small water-pipe winding

backward and forward in the furnace, and terminating at one end at the point at which the feed-water was introduced and at the other uniting with the steam-pipe leading to the engine. Barlow's had a nest of horizontal tubes connected to water-legs at both ends. Stevens's had slightly inclined tubes, closed at one end and connected to a water-chamber at the other.

Some More Recent Forms.—The following notes, with accompanying illustrations, are taken by permission from "Facts," a pamphlet

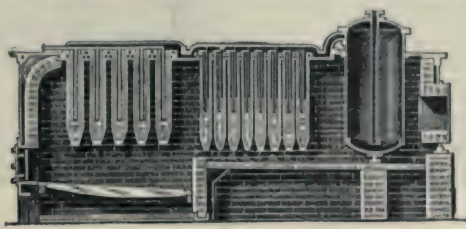

FIG. 103.—JOLY, 1857.

published by The Babcock & Wilcox Co. in 1895. They show a few of a great number of designs of water-tube boilers that have been made by varying the form or arrangement of four elementary units, viz.:

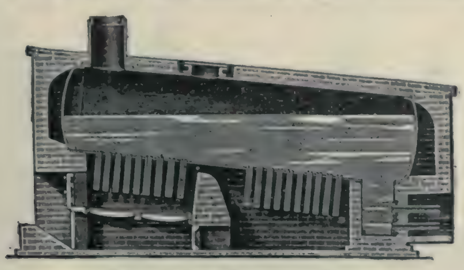

FIG. 104.—FIELD, 1866.

1, a tube closed at one end; 2, a bent tube; 3, an aggregation of pipes and fittings; 4, a group of straight tubes connected with water-chambers at each end.

BOILERS WITH CLOSED-END TUBES.

Joly, 1857.—A sectional boiler with vertical drop-tubes, each fed by an internal tube extending nearly to the bottom.

Field, 1866.—A cylinder boiler with radiating drop-tubes fitted to the lower side. Field also used circulating tubes inside of the drop-tube.

Fletcher, 1869.—A vertical fire-box boiler, with horizontal cone-

shaped tubes radiating from the sides of the fire-box towards the centre.

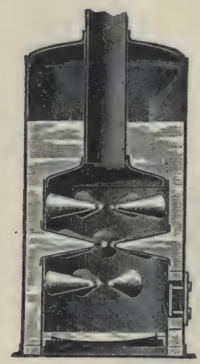

FIG. 105.—FLETCHER, 1869.

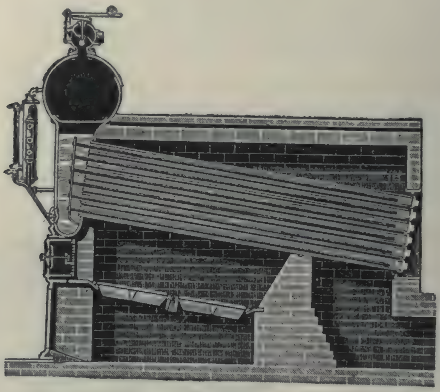

FIG. 106.—MILLER, 1870.

J. A. Miller, 1870.—Cast headers, to which were fixed closed-end tubes, inclined about 15° from the horizontal, with inner circulating tubes.

Allen, 1871.—Cast-iron drop-tubes slightly inclined from the vertical, screwed into a horizontal tube at the top.

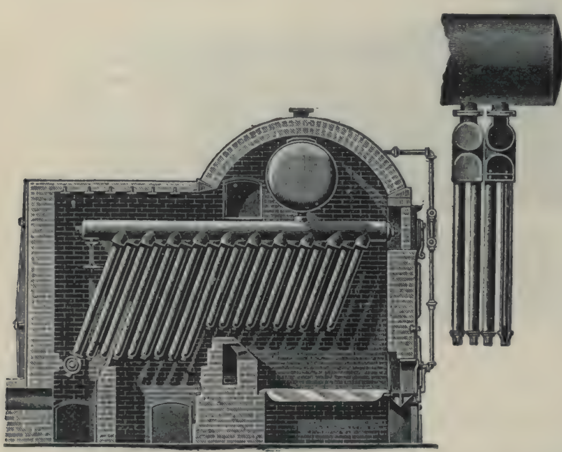

FIG. 107.—ALLEN, 1871.

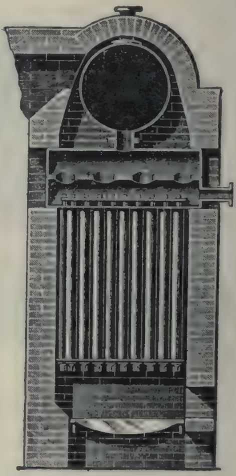

FIG. 108.—WIEGAND, 1872.

Wiegand, 1872.—Groups of vertical tubes, with inside circulating tubes, connected to an overhead steam- and water-reservoir. The lower ends of the tubes were closed by caps.

W. A. Kelly, 1876.—Similar to J. A. Miller's design of 1870, with some additions, among them being superheating tubes for drying the steam.

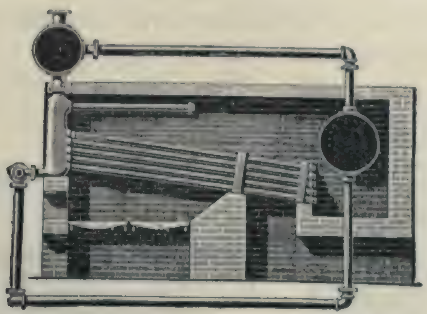

FIG. 109.—W. A. KELLY, 1876.

Hazelton, 1883.—A vertical cylinder with radial tubes, commonly called the "Porcupine" boiler. The upper portion of this boiler is superheating surface.

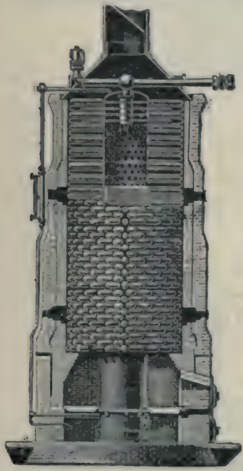

FIG. 110.—HAZELTON, 1883.

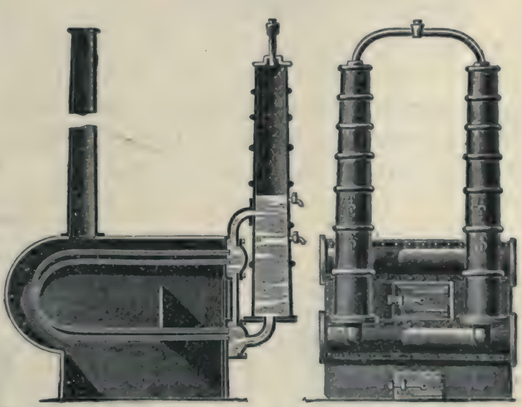

FIG. 111.—GURNEY, 1826.

BOILERS WITH BENT TUBES.

Gurney, 1826.—A pair of vertical steam- and water-reservoirs were connected at their bottom and about half way up their height by cross-pipes, from which a series of bent tubes were projected into the fire-box. The lower row of tubes served as a grate. This boiler was used in a steam road-carriage.

Church, 1832.—A locomotive fire-box with a vertical extension at one end, filled with bent tubes connecting the sides of the fire-box with the crown-sheet, and with side openings in the shape of fire-tubes extending through the shell at the top, for taking off the gases. This boiler was also used for a road-carriage.

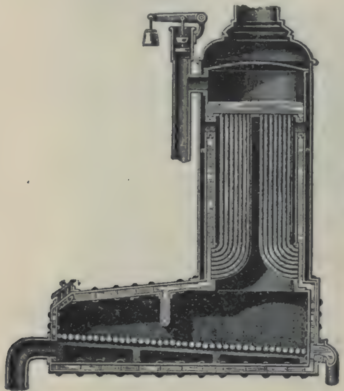

FIG. 112.—CHURCH, 1832.

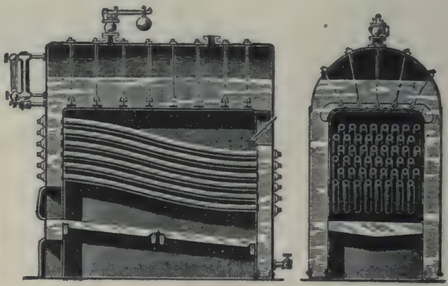

FIG. 113.—WILCOX, 1856.

Wilcox, 1856.—Stephen Wilcox was the first to use inclined tubes connecting water-spaces, front and rear, with an overhead steam- and water-reservoir. The tubes were bent with a slightly reversed curve extending nearly the whole length of the tube. In 1869 Mr. Wilcox, with his partner, George H. Babcock, brought out the Babcock & Wilcox boiler, with straight inclined tubes.

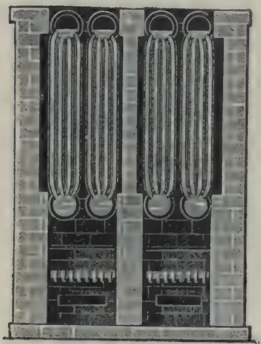

FIG. 114.—ROWAN, 1865.

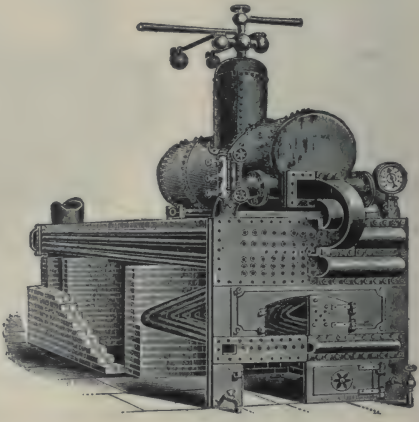

FIG. 115.—PHLEGER, 1871.

Rowan, 1865.—A series of units placed side by side, each unit consisting of an upper and a lower horizontal drum connected by a series of bent-ended heating-tubes, and at their ends, outside the setting, with down-take tubes of large diameter.

Phleger, 1871.—Gurney U tubes were used for fire-bars, with a second series added above for heating-tubes and above them a large steam- and water-drum.

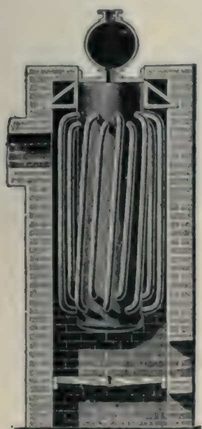

FIG. 116.—ROGERS & BLACK, 1876.

FIG. 117.—DANCE, 1833.

Rogers & Black, 1876.—A series of U tubes on the outside of a vertical shell, surrounded with a brick setting.

BOILERS BUILT OF PIPES AND FITTINGS.

Dance, 1833.—The lower tubes were used as grates. Up-flow and down-flow pipes, connected by special fittings. Steam and water capacity very small, and no provision for internal cleaning.

Belleville, 1865.—Bent U tubes screwed into return bends, a series of coils being placed vertically side by side, connected at the top to a separating-drum and at the bottom to a common feed-pipe.

Belleville, 1877.—The bent pipe was discarded and return bends used at both ends of a series of straight tubes.

Kilgore, 1874.—Straight tubes with return bends, connected to cast-iron water-chambers. This boiler was introduced quite extensively in Pittsburgh, but it had a very short life.

Ward, 1879.—A vertical cylinder, surrounded by a series of concentric coils interrupted twice in their circumference, on opposite

sides, by vertical manifolds. The manifolds on one side were connected by a radial pipe to the bottom on the cylinder, and at the other side to a circular pipe connecting near the top of the cylinder.

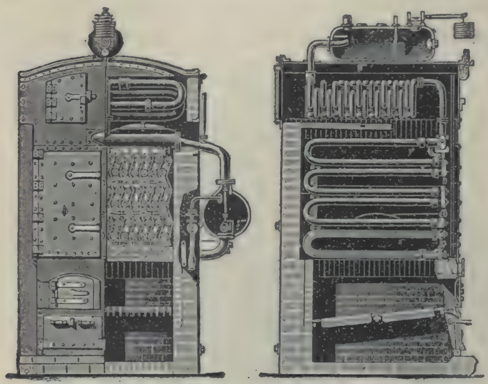

FIG. 118.—BELLEVILLE, 1865.

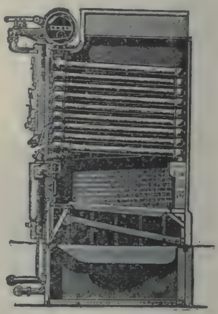

FIG. 119.—BELLEVILLE, 1877.

Roberts, 1887.—Straight pipes with return bends, with "downtake" pipes outside.

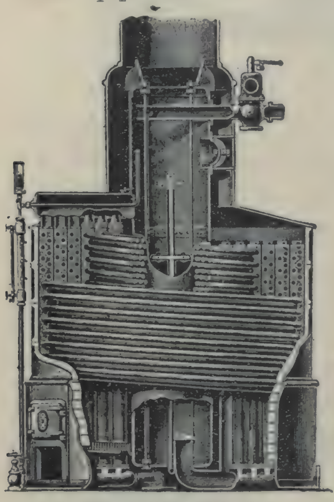

FIG. 120.—WARD, 1879.

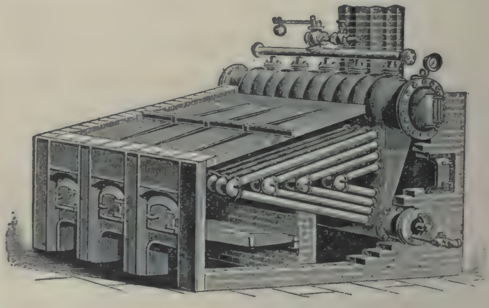

FIG. 121.—KILGORE, 1874.

Almy, 1890.—Straight pipes connected with elbows and return bends to an overhead steam- and water-reservoir and bottom connecting pipes.

Herreshoff, 1890.—Straight tubes with return bends at each end.

FIG. 122.—ROBERTS, 1887.

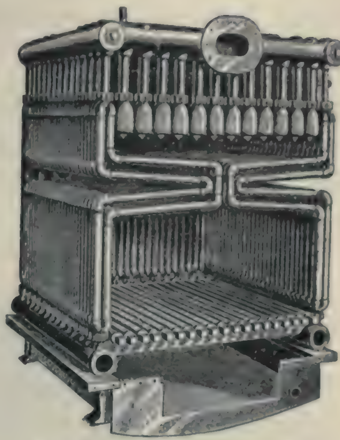

FIG. 123.—ALMY, 1890.

BOILERS WITH STRAIGHT TUBES CONNECTED TO WATER-CHAMBERS AT BOTH ENDS.

Firmenich, 1875.—Flat-sided horizontal drums at top and bottom of a bank of straight tubes. Two such units were placed A-

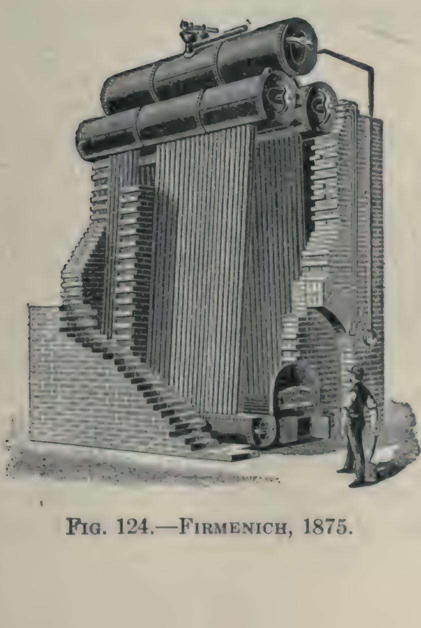

FIG. 124.—FIRMENICH, 1875.

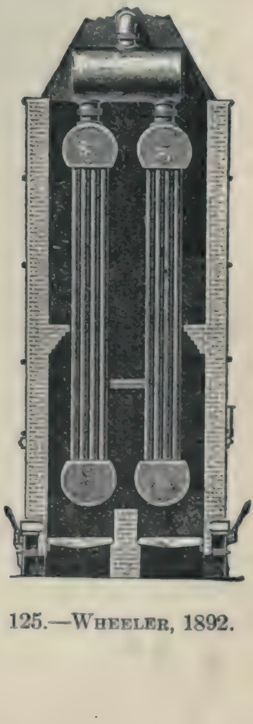

FIG. 125.—WHEELER, 1892.

fashion, with the grates between them at the bottom, and surmounted with a steam-drum on top.

Wheeler, 1892.—Like the Firmenich, but with the tubes set vertically, and the lower water-drums directly over the grates.

Maynard, 1870.—A horizontal steam- and water-cylinder above a bank of tubes placed at a slight inclination from the horizontal; the ends of the tubes expanded into round boxes having stayed heads connected to the horizontal drum.

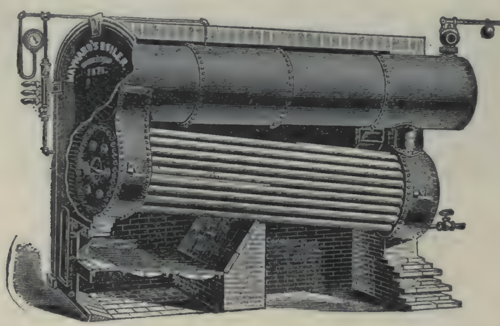

FIG. 126.—MAYNARD, 1870.

Illustrations of some other old forms of boilers will be found in the chapter on Results of Steam-boiler Trials.

Modern Forms of Water-tube Boilers.—The water-tube type of boiler did not come into any extensive use prior to 1870, probably because inventors of the earlier forms did not appreciate the requirements of a thoroughly good boiler, such as facility for cleaning and repair, provisions for proper circulation of the water and of the gases of combustion, and for insuring dry steam—all of which are met in at least some of the modern forms of the water-tube boiler. In 1867 Mr. John B. Root invented what is known as the Root boiler, and in 1869 the Babcock & Wilcox Company first put their boiler on the market. Both of these boilers have been improved in some respects since they were first brought out, the Babcock & Wilcox reaching practically its present form as early as 1873, and the Root boiler its present form about ten years later.

The Babcock & Wilcox Boiler, since the original patents have expired, has been extensively copied, with modifications more or less important, and its general form may now be considered a standard type of boiler, the leading features of which are a horizontal drum,

usually about 36 in. diameter, the water-line being carried at the middle of the drum, and a "bank" of 4-in. tubes inclined about 15° from the horizontal, the tubes being usually laid parallel in horizontal rows across the boiler, the vertical rows being staggered. The tubes are expanded at each end into headers, which take different forms in different modifications of the general type. The front headers are

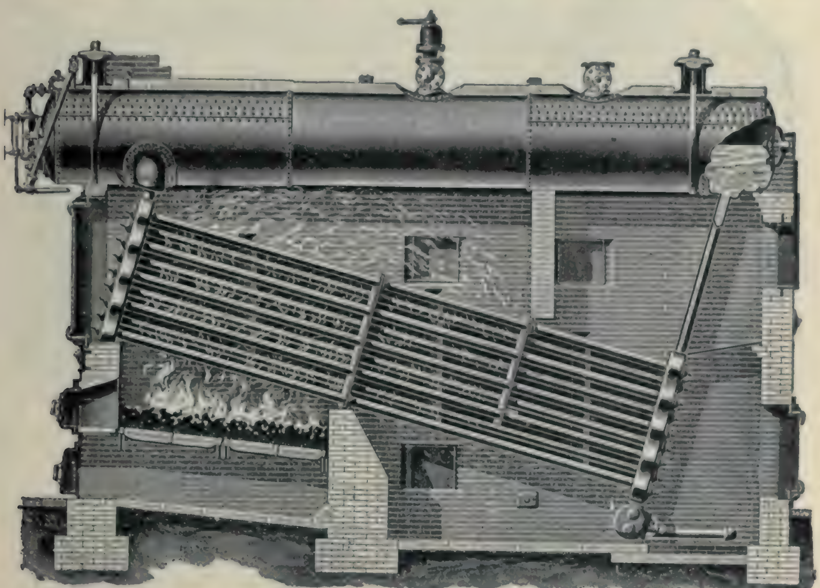

FIG. 127.—THE BABCOCK & WILCOX BOILER, ANTHRACITE SETTING.

connected with the drum by short pieces of tube, and the rear headers by tubes 4 to 6 ft. long.

In the most recent form of Babcock & Wilcox boiler, designed especially for high pressures, Fig. 127, the header is a long corrugated box of forged steel, into which are expanded the tubes of one of the vertical staggered rows. Opposite the end of each tube there is a hand-hole plate, held to its seat by a bolt and nut. As the rear header, as well as the front header, is provided with similar hand-hole plates, the interior of the tube may be inspected by the boiler-owner himself, by having some one hold a candle at the hand-hole of the rear header while he looks in through the front header. The hand-holes are made of such a size that the tubes may be withdrawn or inserted through them whenever a tube requires to be replaced.

The furnace shown in Fig. 127 is suitable only for anthracite or coke. With soft coal it would make dense smoke and cause the tubes to be coated with soot.

In the *National* and *Gill* boilers, the principal feature of difference from the Babcock & Wilcox boiler is the form of the headers. In the National boiler the header is of approximately a triangular shape to take three tubes, while in the Gill boilers the headers are made. as shown in Fig. 128, to take four, five, or six tubes. Each header-box is connected with the one above it by an expanded nipple.

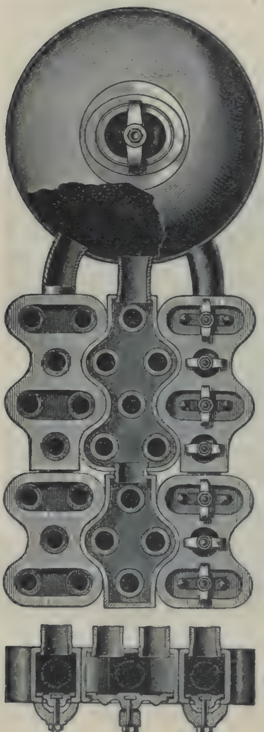

FIG. 128.—HEADERS OF THE GILL BOILER.

The Root Boiler (Fig. 129), consists of an arrangement of 4-in. tubes, inclined about 20° from the horizontal and set in a staggered position vertically, surrounded by several horizontal steam- and water-drums about 15 ins. in diameter. The tubes are expanded into headers which with their connections form a vertical channel through which the water passes from the point where the lower tube enters them to the top. When the boiler is working, water fills the tubes, and also about half of each of the overhead drums, each one of which receives the water and steam from the vertical piles of tubes immediately below it.

In the rear of the boiler, at the end of the overhead water-drums, each drum has a vertical pipe terminating in a drum common to all beneath it, which is placed at right angles to them; and through these vertical "down-take pipes" flows the water of circulation, which has parted with its bubbles of steam. In this cross-drum the down-flowing water meets the feed-water, which is introduced at this point, and warms it up to a temperature sufficiently high to prevent any trouble which might be caused by unequal expansion in the boiler parts from receiving feed-water at a low temperature. From this feed-drum, the mixture of feed and circulating water descends through the large vertical down-take pipes to the mud-drum beneath. After leaving the mud drum, the water passes from the "goose-neck" connections into

the extreme lower end of each one of the rear vertical sections of boiler-tubes; and then it rises up along the tubes, maintaining the constant upward flow which is always going on when the boiler is in operation.

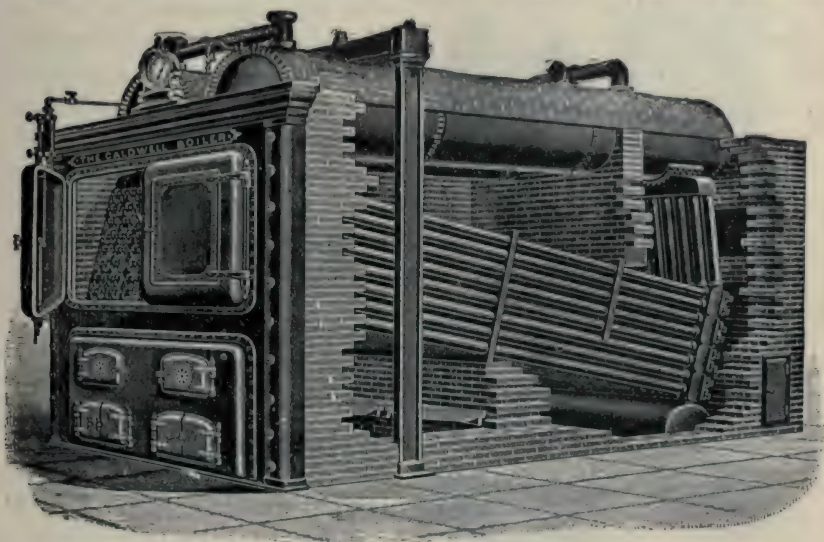

FIG. 129.—THE ROOT WATER-TUBE BOILER.

The details of the Root boiler are shown in Fig. 130.

No. 1 shows a "package" consisting of two tubes with a header expanded on each end. No. 2 shows these packages placed one upon the other, forming a section. Connecting-bends are also shown in place, through which a circulation of water is obtained from the bottom to the top of the section. A number of sections placed side by side go to form a complete boiler. No. 3 shows the method by which these bends are applied. Between the bend which is ready to drop in place and the header is seen the metallic packing-ring which drops into the seat beneath it. This ring is shown in detail in No. 4. A sectional view, No. 6, shows it in place. All these seats are milled to exact size by special machinery, and the ring, which is made of an elastic bronze-like metal, is also finished to an exact size.

The tapered end of the connecting-bend is shown in the enlarged view, No. 5. When this plug is forced down into the tapered seat of the ring it causes the ring to expand in every direction radially, and so make a tight joint. This bend is drawn down into the seat by

bolts. The heads of these bolts are ball-shaped and are received into similarly shaped sockets cast in the headers, which allow the screw-ends freedom to move in every direction.

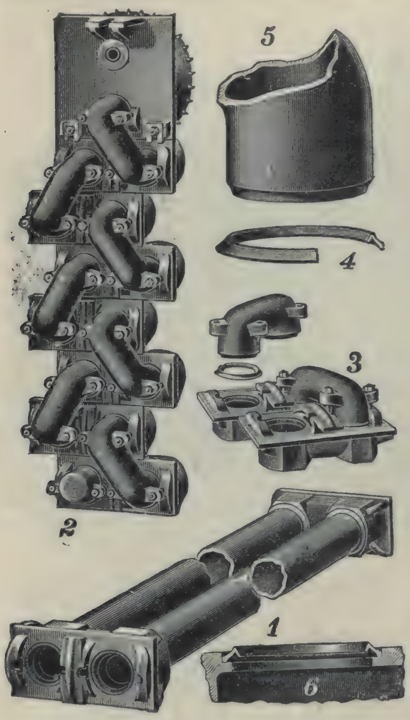

FIG. 130.—DETAILS OF THE ROOT BOILER.

All the water-tube boilers above mentioned, as well as many other variations of this general type, are known as sectional boilers, since they are built up of sections made by assembling a number of interchangeable parts. This sectional feature is a convenience in transportation and erection, and it facilitates the rapid making of repairs, a new section being easily substituted for an old one.

Other water-tube boilers are made which are not sectional. One of the best known is the *Heine* boiler, shown in Fig. 21, p. 219. The tubes are parallel with the drum, both being inclined at the same angle when the boiler is set up, and are connected with it at each end by large water-legs, made of plates stayed together. A hand-hole plate is opposite the end of each tube, through which the tube may be cleaned or replaced.

It will be noticed that in the Heine boiler, Fig. 21, the passages for the gases of combustion are horizontal, or parallel with the tubes, while in the other boilers the gases pass transversely across the tubes three times. For anthracite coal the transverse passages are probably the best, and when properly fired this coal is thoroughly burned on the grates, and the direction of the gas-passages across the tubes offers every facility that can be desired for allowing the heating surface to absorb the heat from the gases. With bituminous coal, the settings shown in Figs. 127 and 129 do not offer sufficient opportunity for the gases from the coal to be thoroughly burned

before they reach the tubes, consequently a portion of the valuable heating gases is apt to go off unburned, since the tubes chill them below the temperature of ignition. The long horizontal passage under the lower row of tubes is better for insuring combustion of the gases, but the return passage enclosing the tubes requires to be carefully proportioned as to its sectional area, in relation to the amount of coal burned, so that the hot gases do not travel along the upper portion of the passage only, leaving the heating surface of the lower portion ineffective. In adopting either one of these styles of setting, with bituminous coal, there is a choice of evils: in one style the gas may be imperfectly burned, in the other the heat from the burned gas may be imperfectly absorbed. With furnaces adapted to the complete combustion of the gases of bituminous coal, the transverse passage will usually be found preferable to the longitudinal.

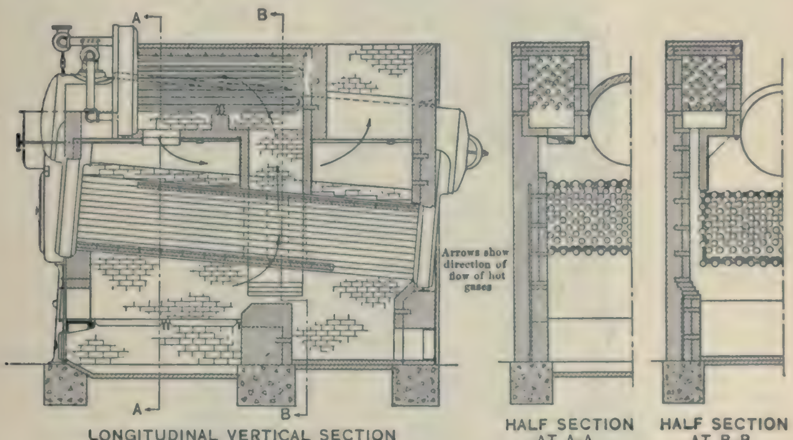

FIG. 131.—HEINE BOILER WITH SUPERHEATER.

The Setting of a Heine Boiler with Superheater is shown in Fig. 131. The superheater consists of two parts, one on each side of the drum. Each superheater is located above the water line, in a fire-brick chamber formed in the setting, as shown. A flue connects the chamber directly with the furnace, and a small per cent of the furnace gases flow up the flue and supply the heat to the superheater tubes. The hot gases pass over the superheater tubes, and then flow out of the superheater chamber at the end nearest the front header, so that before reaching the uptake and joining the boiler gases, they

pass under the boiler drum. A damper in the superheater outlet controls the amount of gases flowing over the tubes, thus permitting temperature regulation and also cutting off the supply of hot gases when saturated steam is desired, or when here is no boiler load. No provision is made for flooding the superheater as that operation is unnecessary.

The superheaters are made of $1\frac{1}{2}$-in. seamless-drawn tubing, bent into U-form, and expanded into box headers of a rectangular shape. Hollow stay-bolts in the headers permit of cleaning of soot from the superheater tubes, and hand-hole plates are provided for access to the tube ends. Within the headers there are two partition plates dividing the superheater box into three chambers and causing the steam to flow through the tubes in four passes.

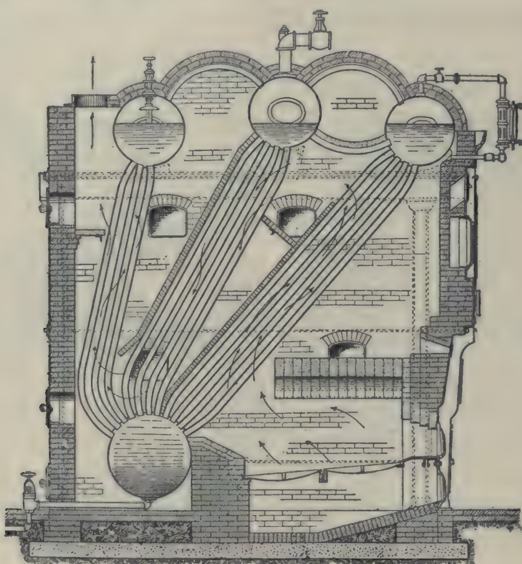

FIG. 132.—THE STIRLING BOILER.

The Stirling Boiler, Fig. 132, consists of three horizontal steam- and water-drums at the top, and a single water-drum at the bottom, connected by three sets of inclined and somewhat curved tubes. A fire-brick arch is built above the grate, and baffle-walls of fire-brick are placed above the upper rows of two of the sets of tubes, which give a proper direction to the heated gases.

The Wickes Boiler, Fig. 133, also consists of an upper and lower drum connected by vertical tubes. By building a thin wall of fire-

brick between two adjoining middle rows of tubes, as shown in the cut, the passage for gas is caused to lead first upwards from the fur-

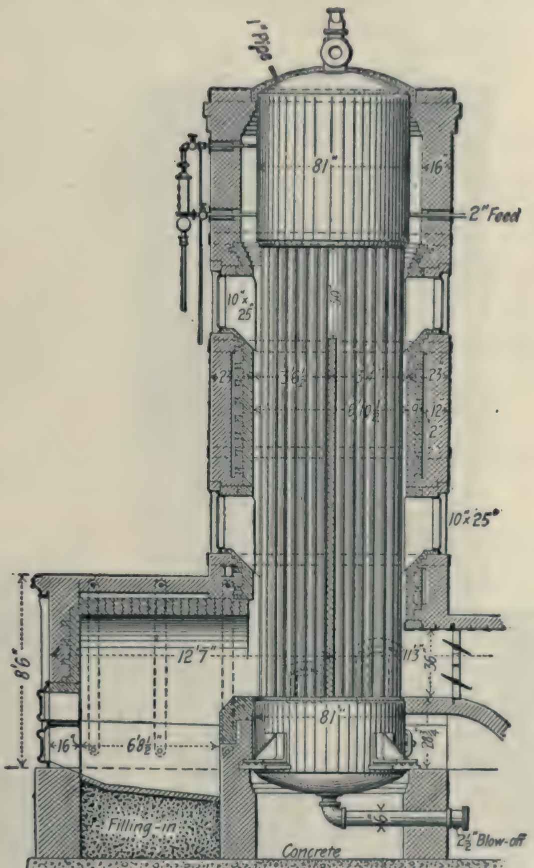

FIG. 133.—THE WICKES BOILER.

nace and then downwards to the chimney-flue. An external furnace is used with this boiler.

The Rust Water-tube Boiler.—This boiler, one style of which is shown in Fig. 134 consists of two transverse steam-and-water drums and two transverse water-and-mud drums, set parallel and connected by banks of tubes. Each steam-and-water drum is placed directly over a water-and-mud drum, with which it is connected by five rows of straight vertical tubes and one row of curved tubes. The rows

of tubes are parallel with the bridge wall for the full width of the furnace. The steam-and-water drums are connected by one row of short circulating tubes below the water line, and by a row of steam tubes connecting the steam spaces above the water line, these steam

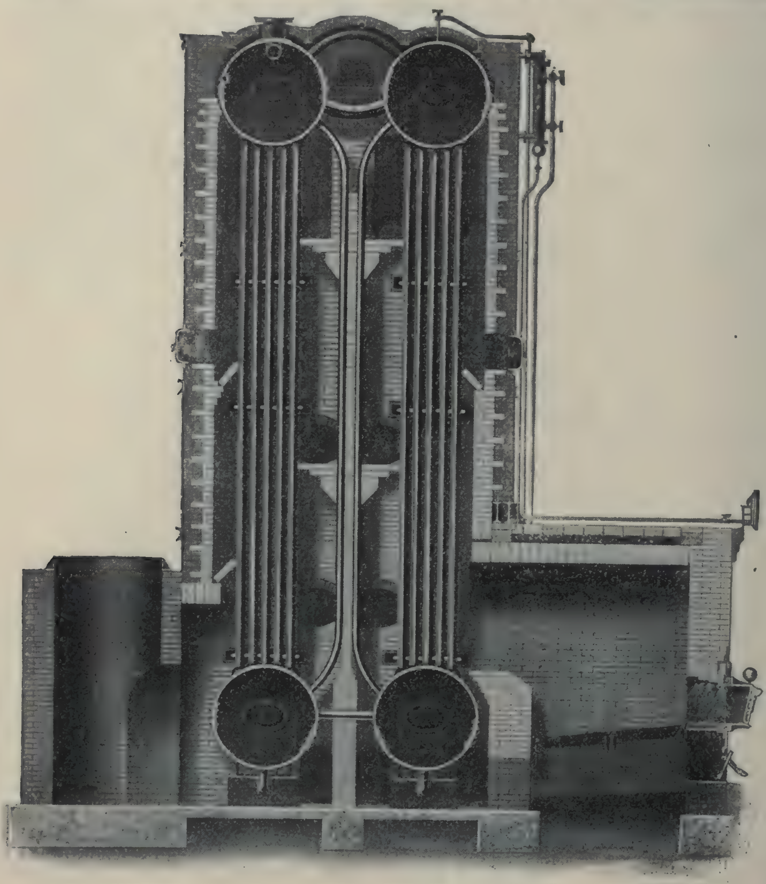

FIG. 134.—THE RUST WATER-TUBE BOILER.

tubes being grouped near the ends of the drums. The main steam outlet is placed at the top and center of the rear steam-and-water drum. The water-and-mud drums are connected by a row of short horizontal circulating tubes.

Each drum is made up of two sheets with longitudinal riveted seams. One of these sheets is pressed to form tube seats which permit

the use of straight tubes expanded direct into the cylindrical drum—(system is patented). The drum heads and manhole plates are of forged steel. The tubes are staggered and spaced so as to leave room between the tubes of the outside rows to remove those of the inner rows, and replace any tube without disturbing any other tube or any of the brickwork. After a defective tube has been removed it is passed out through a door in the side of the setting.

In another style of the Rust boiler the two rows of vertical curved tubes are eliminated and a heavy fire-brick baffle wall supported from the ground is substituted for the lighter baffle wall. This boiler is designed for locations where straight tubes only are desired. The Rust boiler is manufactured by the Babcock & Wilcox Co.

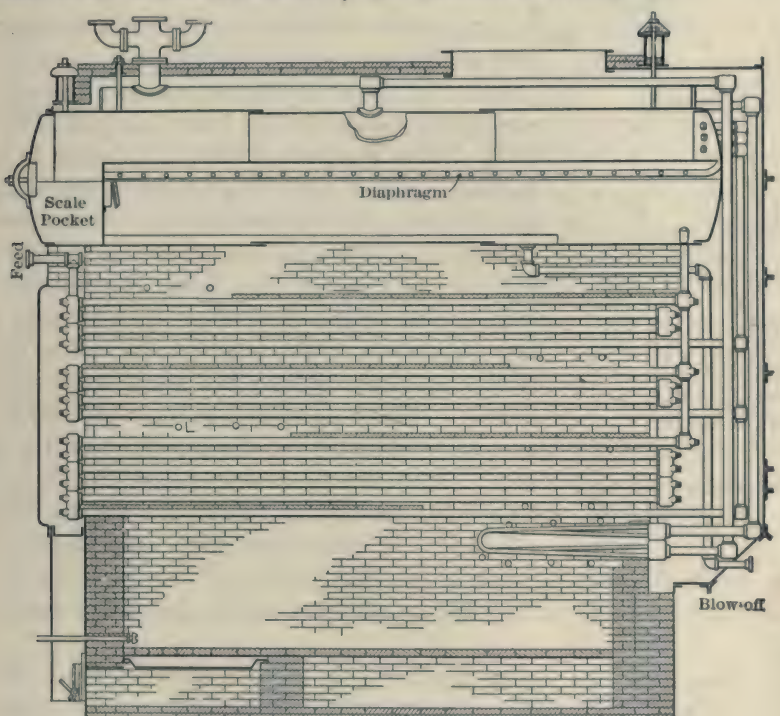

FIG. 135.—THE PARKER BOILER.

The Parker Boiler is shown in Fig. 135. It consists of one or more horizontal steam and water drums mounted above two or more banks of horizontal tubes. Fire-brick tile are supported by the bottom row of tubes in the lowest bank, to form a roof over

the combustion chamber, and above the top row of tubes in each of the banks so as to baffle the gases and cause them to travel along the tubes. Feed water is introduced at one end of the upper bank of tubes and all the banks are supplied with water from the overhead drum through downflow pipes leading from the bottom of the drum (see pipe connection at the right hand of the cut). The water circulates downward through the elements or sections of the upper bank (known as the economizer), being heated as it travels by the gases which have been reduced in temperature by their passage through the lower banks, and is finally discharged through upcast pipes into the rear head of the drum above the diaphragm. The water then flows along the diaphragm into the scale pocket at the other end of the drum, then through a swinging non-return gate covering a manhole leading into the lower chamber of the drum, thence into the downcast circulating pipes into the lower banks of tubes. Each element, or nest of tubes, in the banks is provided with a non-return valve in the inlet box, which prevents the reversal of the flow of water. The boiler shown in the cut is equipped for oil burning, and has a small superheating coil in the combustion chamber and a large superheating drum under the roof of the setting and between the two steam and water drums. It is rated at 645 H.P. or 6450 sq. ft. of heating surface. It contains 280 4-in. tubes, of which 246 are 20 ft. long, 17 are 20.5 ft. and 17 are 22.5 ft. long, two steam and water drums 4½ by 22 ft., one superheater steam drum 18 in. by 20 ft., and 32 loops of 1¼ in. tubes, or 107.5 sq. ft. in the superheating coils. Fig. 136 is a diagram of the circulation system of the Parker boiler.

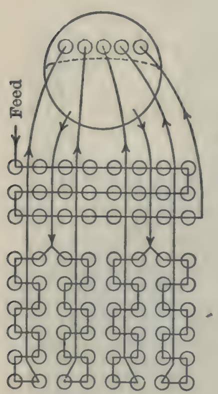

FIG. 136.—CIRCULATION OF THE PARKER BOILER.

Water-tube Marine Boilers.—Of the boilers built of pipes and fittings, briefly described on page 357, the Ward, Roberts, Almy and Herreshoff have been somewhat extensively used in steam-yachts and torpedo-boats. The Belleville, in its recent forms, has come largely into use in the French mercantile marine, and has been adopted in several ships of war, including large cruisers, in the British Navy. For descriptions and illustrations of many other forms of marine water-tube boilers see Bertin & Robertson on "Marine Boilers" and

W. S. Hutton on "Steam-Boiler Construction." Some of these forms are described below.

The Thornycroft Boiler (Fig. 137). A large cylindrical steam-drum is connected to a lower water-drum by two groups of curved eter. The fire-grates are on generating tubes of small diam- each side of the water-drum. The two outer rows of tubes of each group are brought together, making a tube-wall, but so as to leave openings for the hot gases to pass between the tubes near their lower ends. The two inner rows of each group are in like manner brought together, except near their upper ends, where there are passages left between them.

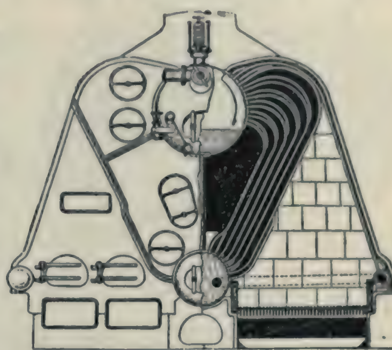

FIG. 137.—THORNYCROFT BOILER.

The gases thus pass from the combustion-chamber above the grates on each side into the flue between the outer and inner tube-walls, and thence into the heart-shaped central flue which leads to the funnel at the back of the boiler. The outer sides of the fire-box or combustion-chamber are formed by tube-walls leading from two small water-drums into the upper part of the steam-drum, these water-drums being connected by a cross-pipe at the back of the boiler. The generating tubes discharge a mingled mass of steam and water into the steam-drum, in which there are baffle-plates to separate the steam and the water. The steam passes into an internal steam-pipe through narrow slits, while the water falls to the bottom of the steam-drum and is thence conveyed by large central return-pipes to the water-drum at the bottom, thus insuring a rapid circulation. The following data of a large Thornycroft boiler are given by Hutton:

Tube surface	sq.ft.	4020
Fire-grate area	"	63.5
Weight of the boiler and mountings, with water	tons	18¼
Indicated horse-power on trial, with triple-expansion engines		2000
Working pressure of steam	lbs. per sq.in.	220

This boiler is known as the "Daring" type. Other and smaller boilers of the Thornycroft make are called the "Speedy" and the "Launch" types. The Thornycroft boiler is largely used in torpedo-boats and high-speed yachts, especially in Great Britain.

The Mosher Boiler (Fig. 138). Two steam- and water-drums communicate with lower water-chambers by a great number of curved tubes of small diameter, and also by two external down-take tubes, 4 inches in diameter. The front and back casings are lined with fire-brick covered with asbestos, and the upper part with a layer of soapstone between layers of asbestos. This boiler is used in many high-speed American yachts.

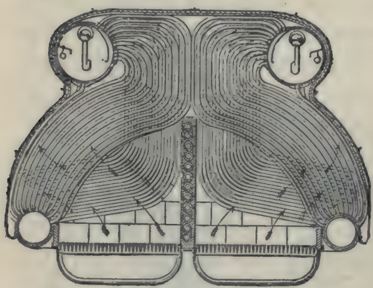

FIG. 138.—THE MOSHER BOILER.

Fig. 139 shows a later form of the Mosher boiler, known as type B. Boilers of this type were used in the U. S. battleships Kearsarge and Kentucky. Another form, type A, is similar to type B, but has two banks of tubes, more steeply inclined than those shown in Fig. 139, connected with a single overhead drum, and placed over a wide A-shaped furnace.

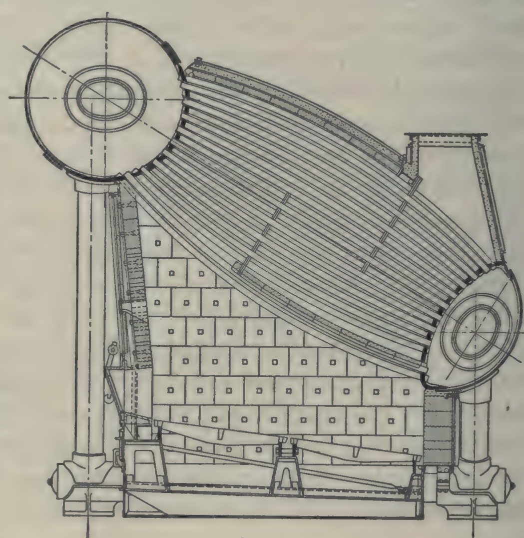

FIG. 139.—MOSHER BOILER, TYPE B.

The Yarrow Boiler, shown in Fig. 276, page 654, is similar in form to the type A Mosher boiler. It is largely used for marine purposes in Europe.

The Babcock & Wilcox Marine Boiler is shown in Fig. 140, which represents one of the boilers of the U. S. cruiser Cincinnati. This boiler has been extensively adopted in the British and American navies for the largest war-vessels, and since 1885 it has been used with great success in the Wilson (British) line of merchant steamers. The chief features in which it differs from the land type of the Babcock &

Wilcox boiler, Fig. 127, page 361, have been designed for the purpose, chiefly, of providing a very large area of grate and heating surface, together with relatively small weight of metal and water to be carried in the contracted space allowed in ocean steamers. The tubes in the

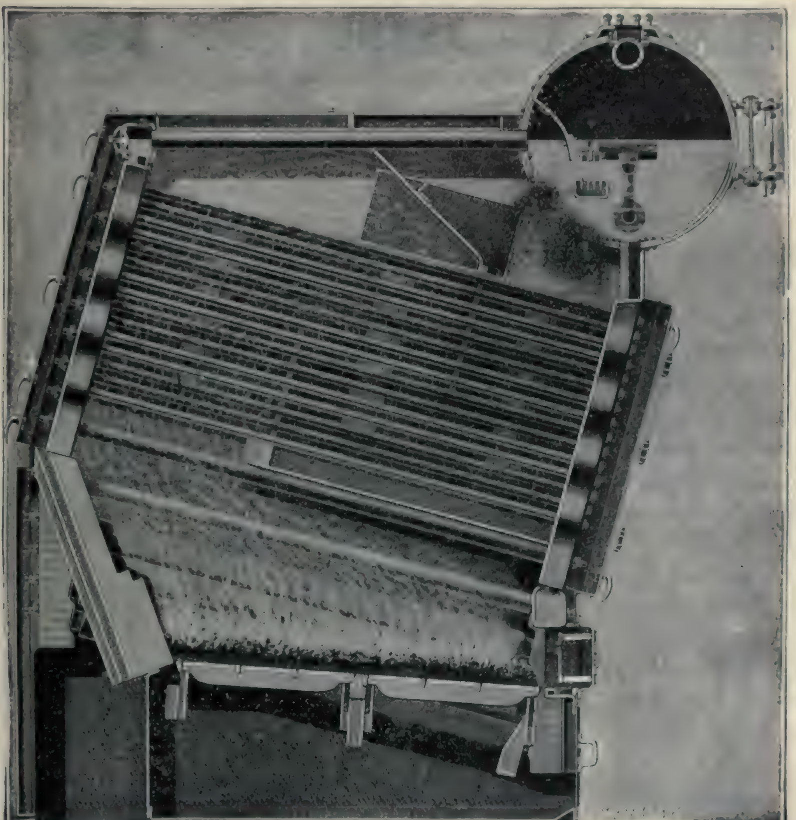

FIG. 140.—LONGITUDINAL SECTION OF BABCOCK & WILCOX MARINE WATER-TUBE BOILER, "ALERT" TYPE, SHOWING SIDE CASING REMOVED.

lower row are 4 ins. diameter, all others being 2 ins. The steam and water drum is set transversely to the direction of the tubes. The fire-box is roofed over by fire-brick supported by the lower row of tubes. The fire-door is placed at what would be called the rear of the boiler in the ordinary land boiler. A fuller description of this boiler, together with the record of a series of tests made by engineers of the

U. S. Navy will be found in the chapter on Results of Steam-Boiler Trials.

Forms of Boiler used in Different Countries.—The average boiler-user is governed in his selection of a boiler largely by local custom and prejudice, and therefore different forms of boiler are the favorites in different parts of the world. To show how generally this is true, we have the following figures showing the percentage of various types of boilers used in Great Britain, France, Germany, Switzerland, and Austria, prepared by Mr. Hiller, of the National Boiler Insurance Co., of Manchester, England, and given by Mr. R. S. Hale in Circular No. 5, 1896, of the Steam Users' Association, Boston Mass.:

PER CENT OF BOILERS OF VARIOUS TYPES USED IN EUROPE.

	1895	1893-4			
	United Kingdom.	France.	Germany.	Switzer-land.	Austria.
Lancashire and similar types	38.0	4.7	35.7	19.6	*
Cornish and similar types	23.7	8.2	15.3	40.8	*
Externally fired cylindrical	†6.8	57.3	14.8	15.5	41.0
Externally fired multi-tubular	....	13.4	5.2	3.5	7.5
Locomotive	11.0	5.1	17.3	5.7	10.5
Small verticals	16.6	3.6	5.0	13.5	6.1
Water-tube	1.8	5.7	4.6	1.4	3.8
Other types	2.1	2.0	2.1	......	1.4

* Lancashire, Cornish and similar types, 29.7. † Including "elephant" boilers

We note from this table that the Lancashire, Cornish, and similar types form a majority of all the boilers in the United Kingdom, Germany, and Switzerland; that the externally fired cylindrical, including the elephant boilers, are in the lead in France and Austria, and that the externally fired multi-tubular boiler, which is the most common boiler in the United States, does not appear to be used at all in Great Britain, and but to a small extent in other European countries. If the table had included boilers in the United States, it would probably put the externally fired multi-tubular boilers far in the lead of all the others, the elephant, the Cornish, and the Lancashire boilers would not appear at all, the externally fired cylindrical boilers to probably less than 5 per cent, the small verticals would have had a larger percentage than in any country in Europe, large verticals, such as the Manning, which are not named in the European list, would have shown a small percentage, and water-tube boilers probably a higher percentage than anywhere in Europe.

It must be said in relation to this table, that it is not fairly representative of European practice in the purchase of new boilers at the present date, but is simply the percentage of boilers in use in 1895, including both old and new; many of them were no doubt forty years old, or more. If a table were prepared of the percentages of boilers of various types now sold, it would undoubtedly show a much higher percentage of water-tube boilers, which have within the last ten years become very common in Belgium, France, and Germany, and are rapidly increasing in favor in England as well as in the United States.

There is nothing in the steam-engine practice of different countries, nor in the character of fuel, or of water used, which will account for the great difference in boiler practice in the different countries, and the only explanation of it appears to be local custom, prejudice, and conservatism. The difference between American and European practice may be partly explained by financial considerations. In England, where manufacturing establishments are generally of many years' standing and provided with abundant capital, and where the interest on money is low, the first cost of a boiler-plant is usually a consideration of secondary importance. This has led to the general introduction of the Lancashire boiler, which is very high in first cost. In America, where most of the manufacturing concerns have grown from small beginnings, where capital for investment in manufacturing has been scarce and interest high, low first cost has been considered of chief importance, and on this account the horizontal multi-tubular boiler, which is almost unknown in England, has come into most extensive use. In recent years, however, in the United States, the increase of wealth, the decrease of the rate of interest, the growth of manufacturing concerns into establishments of vast extent and abundant capital, the decrease of the margin of profit in manufactured goods, and intense competition, have all tended to bring about changes in the ideas and methods of manufacturers and other steam-users. They are now disposed to look more carefully into the questions of economy of fuel and of durability of steam-boilers, and are more willing than formerly to try boilers of higher first cost if they can be assured of an ultimate saving in annual expense.

CHAPTER XI.

BOILER HORSE-POWER—PROPORTIONS OF HEATING AND GRATE SURFACE—PERFORMANCE OF BOILERS.

The Horse-power of a Steam-boiler.—The term "horse-power" has two meanings in engineering: *First, an absolute unit or measure of the rate of work;* that is, of the work done in a certain definite period of time, by a source of energy, as a steam-boiler, a waterfall, a current of air or of water, or by a prime mover, as a steam-engine, a water-wheel, or a wind-mill. The value of this unit, whenever it can be expressed in foot-pounds of energy, as in the case of steam-engines, water-wheels, and waterfalls, is 33,000 foot-pounds per minute. In the case of boilers, where the work done, the conversion of water into steam, cannot be expressed in foot-pounds of available energy, the value given to the term horse-power is the evaporation of 34½ lbs. of water per hour from 212° into steam at the same temperature, which is equivalent, very nearly, to the evaporation of 30 lbs. of water of a temperature of 100° F. into steam at 70 lbs. pressure above the atmosphere. Both of these units are arbitrary; the first, 33,000 foot-pounds per minute, orginally used by James Watt, being considered equivalent to the power exerted by a good London draft-horse, and the second, 30 lbs. of water evaporated per hour, being considered to be the steam requirement per indicated horse-power of an average engine, and 100° F. and 70 lbs. the average conditions of boiler practice (in 1876).

The second definition of the term horse-power *is an approximate measure of the size, capacity, value, or "rating"* of a boiler, engine, water-wheel, or other source or conveyer of energy, by which measure it may be described, bought and sold, advertised, etc. No definite value can be given to this measure, which varies largely with local custom or individual opinion of makers and users of machinery. The nearest approach to uniformity which can be arrived at in the term "horse-power," used in this sense, is to say, that a boiler, engine, water-wheel or other machine, "rated" at a certain horse-power, should be capable of steadily developing that horse-power for a long period of time under ordinary conditions of use and practice, leaving to local custom, to the judgment of the buyer and seller, to written

contracts of purchase and sale, or to legal decisions upon such contracts, the interpretation of what is meant by the term "ordinary conditions of use and practice." (Trans. A. S. M. E., vol. vii. p. 226.)

Definitions of "Boiler Horse-power."—The question of defining the "commercial" horse-power of a steam-boiler was considered by the two committees on steam-boiler trials (1885 and 1899) of the American Society of Mechanical Engineers.* The second committee (1899) reported on this subject as follows:

The Committee recommends that, as far as possible, the capacity of a boiler be expressed in terms of the "number of pounds of water evaporated per hour from and at 212 degrees." It does not seem expedient, however, to abandon the widely-recognized measure of capacity of stationary or land boilers expressed in terms of "boiler horse-power."

The unit of commercial boiler horse-power adopted by the Committee of 1885 was the same as that used in the reports of the boiler-tests made at the Centennial Exhibition in 1876, namely, . . . an evaporation of 30 pounds of water per hour from a feed-water temperature of 100 degrees Fahr. into steam at 70 pounds gauge-pressure, which shall be considered to be equal to 34½ units of evaporation; that is, to 34½ pounds of water evaporated from a feed-water temperture of 212 degrees Fahr. into steam at the same temperature.

The Committee of 1899 accepted the same standard, but reversed the order of two clauses in the statement, and slightly modified them, so as to read as follows:

The unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation per hour; that is, 34½ pounds of water evaporated per hour from a feed-water temperature of 212 degrees Fahr. into dry steam of the same temperature. This standard is equivalent to 33,317 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water temperature of 100 degrees Fahr. into steam at 70 pounds gauge-pressure.†

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* Trans. A. S. M. E., vols. vi. and xii.

† The figure 33,317 is based on the old steam tables, in which an evaporation of 1 lb. of water from and at 212° was equivalent to 965.7 B.T.U. By the new steam tables (Marks and Davis, 1910), in which the value of the thermal unit is $\frac{1}{180}$ of the heat required to raise the temperature of 1 lb. of water from 32° to 212° F., the value of the unit of evaporation is 970.4 B.T.U., and the commercial horse-power is then $34.5 \times 970.4 = 33{,}478.8$ B.T.U. The evaporation of 30 lbs. of water at 100° F. into steam of 70 lbs. gauge pressure is equivalent to 33,461 B.T.U.

The Committee also indorsed the statement of the Committee of 1885 concerning the commercial rating of boilers, changing somewhat its wording so as to read as follows:

A boiler rated at any stated capacity should develop that capacity when using the best coal ordinarily sold in the market where the boiler is located, when fired by an ordinary fireman, without forcing the fires, while exhibiting good economy; and further, the boiler should develop at least one-third more than the stated capacity when using the same fuel and operated by the same fireman, the full draft being employed and the fires being crowded; the available draft at the damper, unless otherwise understood, being not less than ½ inch water-column.

The A. S. M. E. Committee on Power Tests, in its revised report, (1915) omitted the above statement in view of the facts that in modern power plant practice, with mechanical stokers, forced draft and gas analyses, boilers are often called upon to develop during times of "peak load" from two to three times their normal rating, and that the overload capacity of a boiler depends more upon the furnace conditions than upon the boiler itself. It reaffirmed the definition of a boiler horse-power as an evaporation of 34.5 lbs. of water per hour from and at 212°, and said:

Contracts for power-plant apparatus should specify the leading dimensions of the apparatus and its rated capacity. If a specific guarantee of capacity is made, either working or maximum capacity, the operating conditions under which the guarantee is to be met should be clearly set forth; such, for example, as steam pressure, speed, vacuum, quality of fuel, force of draft, etc. Likewise if a contract contains a guarantee of economy all the conditions should be fully specified.

The commercial rating of capacity determined on for power-plant apparatus, whether for the purpose of contracts for sale, or otherwise, should be such that a sufficient reserve capacity beyond the rating is available to meet the contingencies of practical operation; such contingencies, for example, as the loss of steam pressure and capacity due to cleaning fires, inferior coal, oversight of the attendants, sudden demand for an unusual output of steam or power, etc.

Measures for Comparing the Duty of Boilers.—The measure of the efficiency of a boiler is the number of pounds of water evaporated per pound of combustible of a stated quality, the evaporation being reduced to the standard of "from and at 212°"; that is, the equivalent evaporation from feed-water at a temperature of 212° F. into steam at the same temperature.

Efficiency is usually expressed as a percentage, and it is defined as follows:

Efficiency of the boiler and furnace

$$= 100 \times \frac{\text{Heat absorbed per pound of combustible burned}}{\text{Heating value of 1 lb. of combustible}};$$

Efficiency of the boiler furnace and grate

$$= 100 \times \frac{\text{Heat absorbed per pound of coal fired}}{\text{Heating value of 1 lb. of coal}}.$$

The heat absorbed is the product of the pounds of water evaporated per pound of coal (or combustible) by 970.4. Combustible is defined as coal free of moisture and ash.

The measure of the capacity of a boiler is the number of pounds of water evaporated from and at 212° F. per hour, or it is the amount of "boiler horse-power" developed, a horse-power being defined as the evaporation of 34½ lbs. of water per hour from and at 212°.

The measure of relative rapidity of steaming of boilers is the number of pounds of water evaporated from and at 212° per hour per square foot of water-heating surface.

The measure of relative rapidity of combustion of fuel in boiler-furnaces is the number of pounds of coal burned per hour per square foot of grate surface.

Proportions of Grate and Heating Surface required for a given Commercial Horse-power.—(1 H.P. = 34.5 lbs. from and at 212° F.)

Average proportons for maximum economy for land boilers fired with good anthracite coal (ordinary hand firing):

Heating surface per horse-power	11.5	sq. ft.
Grate " " "	1/3	"
Ratio of heating to grate surface	34.5	"
Water evaporated from and at 212° per sq. ft. H.S. per hour	3	lbs.
Combustible burned per H.P. per hour	3	"
Coal with 1/6 refuse, lbs. per H. P. per hour	3.6	"
Combustible burned per sq. ft. grate per hour	9	"
Coal with 1/6 refuse, lbs. per sq. ft. grate per hour	10.8	"
Water evaporated from and at 212° per lb. combustible	11.5	"
" " " " " " " " coal (1/6 refuse	9.6	"

Heating Surface.—For maximum economy,* with any kind of fuel a boiler should be proportioned so that at least one square foot of heat-

* The word "economy" in this paragraph means economy of fuel only. For total economy of annual expenditure, the first cost of plant, interest, taxes, depreciation, etc., must also be considered.

ing surface should be given for every 3 lbs. of water to be evaporated from and at 212° F. per hour. Still more liberal proportions are required if a portion of the heating surface has its efficiency reduced by: 1. Tendency of the heated gases to short-circuit; that is to select passages of least resistance and flow through them with high velocity, to the neglect of other passages. 2. Deposition of soot from smoky fuel. 3. Incrustation. If the heating surfaces are clean, and the heated gases pass over them uniformly, little if any increase in economy can be obtained by increasing the heating surface beyond the proportion of 1 sq. ft. to every 3 lbs. of water to be evaporated, and with all conditions favorable but little decrease of economy will take place if the proportion is 1 sq. ft. to every 4 lbs. evaporated; but in order to provide for driving of the boiler beyond its rated capacity, and for possible decrease of efficiency due to the causes above named, it is better to adopt 1 sq. ft. to 3 lbs. evaporation per hour as the minimum standard proportion.

Where economy may be sacrificed to capacity, as where fuel is very cheap, it is customary to proportion the heating surface much less liberally. The following table shows approximately the relative results that may be expected with different rates of evaporation, with anthracite coal:

Lbs. water evaporated from and at 212° per sq.ft. heating surface per hour:										
2	2.5	3	3.5	4	5	6	7	8	9	10
Sq.ft. heating surface required per horse-power:										
17.3	13.8	11.5	9.8	8.6	6.8	5.8	4.9	4.3	3.8	3.5
Ratio of heating to grate surface if 1/3 sq.ft. of G. S. is required per H.P.:										
52	41.4	34.5	29.4	25.8	20.4	17.4	13.7	12.9	11.4	10.5
Probable relative economy:										
100	100	99	98	95	92	88	84	80	75	70
Probable temperature of chimney-gases, degrees F.:										
450	450	470	490	520	580	650	710	770	850	930

The relative economy will vary not only with the amount of heating surface per horse-power, but with the efficiency of that heating surface as regards its capacity for transfer of heat from the heated gases to the water, which will depend on its freedom from soot and incrustation, and upon the circulation of the water and the heated gases.

The efficiency with any kind of fuel will depend greatly upon the amount of air supplied to the furnace in excess of that required to

support combustion. With strong draft and thin fires this excess may be very great, causing a serious loss of economy. This subject has been fully discussed in Chapter IX.

With bituminous coal the efficiency will largely depend upon the thoroughness with which the combustion is effected in the furnace.

Ratio of Heating to Grate Surface.—In the early days of steam boiler practice, when boilers of 100 H.P. were considered large, and the customary rate of burning coal was from 8 to 10 lbs. per square foot of grate surface per hour, the ratio of heating to grate surface was considered to be a most important factor in boiler design, and as one writer says, it was "a fundamental and almost initial point of attack in the comprehensive subject of steam power-plant design." It is no longer an "initial point of attack"; it is merely a figure that may be obtained, after the design is completed, by dividing the heating surface by the grate surface, if the figure is desired for reference or comparison.

Measurement of Heating Surface.—The usual rule is to consider as heating surface all the surfaces that are surrounded by water on one side and by flame or heated gases on the other, using the external instead of the internal diameter of tubes for greater convenience in calculation, the external diameter of boiler-tubes usually being made in even inches or half inches. This method, however, is inaccurate in the case of a fire-tube boiler, for the true heating surface of a fire-tube is the side exposed to the hot gases, i.e., the inner surface. The resistance to the passage of heat from the hot gases on one side of a tube or plate to the water on the other consists almost entirely of the resistance to the passage of the heat from the gases into the metal, the resistance of the metal itself and that of the wetted surface being practically nothing.*

RULE for finding the heating surface of horizontal tubular boilers: Take the dimensions in inches. Multiply two-thirds of the circumference of the shell by its length; multiply the sum of the circumferences of all the tubes by their common length; to the sum of these products add two-thirds of the area of both tube-sheets; from this sum subtract twice the combined area of all the tubes; divide the remainder by 144 to obtain the result in square feet.

RULE for finding the heating surface of vertical tubular boilers: Multiply the circumference of the fire-box (in inches) by its height

* See paper by C. W. Baker, Trans. A. S. M. E., vol. xix, p. 571.

above the grate; multiply the combined circumference of all the tubes by their length, and to these two products add the area of the lower tube-sheet; from this sum subtract the area of all the tubes, and divide by 144: the quotient is the number of square feet of heating surface.

RULE for finding the square feet of heating surface in tubes: Multiply the number of tubes by the diameter of a tube in inches, by its length in feet, and by 0.2618.

Ratio of Superheating Surface to Boiler Heating Surface.—*Power* of May, 1906, publishes three charts, furnished by R. Ewald, from Riga, Russia, showing the square feet of superheating surface for different areas of boiler heating surface and for different percentages of boiler heating surface situated below the superheater tubes. They are said to be based on the supposition that 3.5 lbs. of steam are generated per hour per square foot of boiler surface, and the three charts are to be used respectively for oil of about 18,500 B.T.U., for coal of about 13,500 B.T.U., and for wood, peat and similar fuel of about 6000 B.T.U. per lb. heating value. The charts are all straight line diagrams, corresponding approximately to the following formulae:

$$\text{for oil, } S = \frac{P(B + 500)}{450}; \quad \text{for coal, } S = \frac{P(B + 400)}{350};$$
$$\text{for wood, } S = \frac{P(B + 300)}{200},$$

in which S = superheating surface, B = boiler heating surface, P = percentage of the boiler surface that is below the superheater tubes. No authority or experimental basis is given for the charts.

Horse-power, Builder's Rating. Heating Surface per Horse-power.—It is a general practice among builders to furnish from 10 to 12 square feet of heating surface per horse-power, but as the practice is not uniform, bids and contracts should always specify the amount of heating surface to be furnished. Not less than one-third square foot of grate surface should ordinarily be furnished per horse-power in order that the boiler may be able to develop from 30 to 50 per cent more than its stated power for short periods in emergencies; but a smaller proportion may be sufficient with free-burning coal and strong draft. See "Grate Surface," below.

Horse-power of Marine and Locomotive Boilers.—The term horse-power is not generally used in connection with boilers in marine practice, or with locomotives. The boilers are designed to suit the engines, and are rated by extent of grate and heating surface only.

Grate Surface.—The amount of grate surface required per horse-power, and the proper ratio of heating surface to grate surface are extremely variable, depending chiefly upon the character of the coal and upon the rate of draft. With good coal, low in ash, approximately equal results may be obtained with large grate surface and light draft and with small grate surface and strong draft, the total amount of coal burned per hour being the same in both cases. With good bituminous coal, like Pittsburg, low in ash, the best results apparently are obtained with strong draft and high rates of combustion, provided the grate surfaces are cut down so that the total coal burned per hour is not too great for the capacity of the heating surface to absorb the heat produced.

With coals high in ash, especially if the ash is easily fusible, tending to choke the grates, large grate surface and a slow rate of combustion are required, unless means, such as shaking grates, are provided to get rid of the ash as fast as it is made.

The amount of grate surface required per horse-power under various conditions may be estimated from the following table:

	Lbs. Water from and at 212° per lb. Coal.	Lbs. Coal per H.P. per hour.	Pounds of Coal Burned per square foot of Grate per hour.								
			8	10	12	15	20	25	30	35	40
			Sq. ft. Grate per H.P.								
Good coal and boiler,	10	3.45	.43	.35	.28	.23	.17	.14	.11	.10	.09
	9	3.83	.48	.38	.32	.25	.19	.15	.13	.11	.10
Fair coal or boiler,	8.61	4	.50	.40	.33	.26	.20	.16	.13	.12	.10
	8	4.31	.54	.43	.36	.29	.22	.17	.14	.13	.11
	7	4.93	.62	.49	.41	.33	.24	.20	.17	.14	.12
Poor coal or boiler,	6.9	5	.63	.50	.42	.34	.25	.20	.17	.15	.13
	6	5.75	.72	.58	.48	.38	.29	.23	.19	.17	.14
	5	6.9	.86	.69	.58	.46	.35	.28	.23	.22	.17
Lignite and poor boiler,	3.45	10	1.25	1.00	.83	.67	.50	.40	.33	.29	.25

In designing a boiler for a given set of conditions, the grate surface should be made as liberal as possible, say sufficient for a rate of combustion of 10 lbs. per square foot of grate for anthracite, and 15 lbs. per square foot for bituminous coal, and in practice a portion of the grate surface may be bricked over if it is found that the draft, fuel, or other conditions render it advisable.* In earlier times, when plain

* These figures apply only to hand firing. With modern types of mechanical stokers with abundant air supply and very large combustion chambers, as much as 40 to 50 lbs. may be burned per hour per square foot of the horizontal area of the furnace, and there is a tendency to increase these amounts.

cylinder and two-flue boilers were in common use, it was customary to have a ratio of say 1 to 20, or 1 to 25, of grate to heating surface. With very slow rates of combustion these proportions gave a fair degree of economy, but as boilers were driven faster, the economy fell off, and the loss of heat in the chimney gases became excessive. This was corrected by the introduction of horizontal tubular boilers, in which the grate surface remaining the same, the extent of heating surface was increased until the ratio of grate to heating surface became 1 to 30. When water-tube boilers came largely into use it was found that the highest economy could be obtained with a ratio of 1 to 40 or 1 to 50. In recent years it has become quite common to pile up heating surface on a given area of grate, so that ratios of 1 to 60 are not infrequent. The evident advantage of such a ratio is that it enables a given horse-power to be built on a smaller ground-space than before, and by using tubes 18 feet long instead of 14, and piling tubes 10 or 15 rows high instead of 7 or 8, the first cost of a given horse-power is reduced. With anthracite egg coal, or with semi-bituminous coal low in ash, and with a strong draft, no disadvantage results from this method of construction; but with poorer coals, such as pea, buckwheat, and rice, and the bituminous coals of Western states, high in moisture, sulphur, and ash, there is a most serious disadvantage, namely, that of cutting down the working capacity of the boiler. A water-tube boiler with 2000 sq. ft. of heating surface and 40 sq. ft. of grate surface, having a ratio of 50 to 1, and rated at 200 H.P., may easily be driven with semi-bituminous or with Pittsburg coal, the draft being sufficient, to over 300 H.P., while with a poor grade of Illinois coal, or with buckwheat anthracite, it would be difficult to drive the boiler up to its rating. With ordinary grates and hand-firing with such coals, increasing the draft beyond a certain amount does not increase the coal-burning capacity, for rapid driving only causes the ash to accumulate more rapidly and to fuse into clinker, choking the draft through the coal and necessitating frequent cleaning. Shaking-grates may remedy the trouble to some extent, but the best remedy is an increase of the area of grate surface and a slower rate of combustion.

In drawing specifications for bids upon boilers it is quite as essential that the extent of grate surface should be specified as the extent of heating surface, especially when the coal to be used is of a poor quality. When two competing boilermakers offer boilers of the same type and the same extent of heating surface, that one should be pre-

ferred, other things being equal, which has the larger grate surface. It may be driven to a greater capacity than the other, to meet emergencies, or it will give the same capacity with a poor grade of coal that the other will give with better coal. Too large a grate surface is an evil that may easily be remedied, by shortening the grates, but too small grate surface necessitates the use of the higher priced coals, entails more labor in handling fires, more frequent cleaning of fires, and consequent loss of economy.

Boilers are usually sold on the basis of rated horse-power, from 10 to 12 square feet of heating surface being taken as equivalent to a horse-power, but of two boilers, each of the same rating on this basis, but one having say 40 sq. ft. of grate and the other 60, the latter, with a poor grade of coal, will develop almost 50 per cent greater power than the former and will give almost the same economy. With a free-burning coal, low in ash, and ample draft, the boiler with 40 sq. ft. of grate may develop 30 or 40 per cent above its rating, and the one with 60 sq. ft. nearly 100 per cent above rating, but in this case, the boiler with large grate surface will show a great loss of economy, because it is overdriven.

Proportions of Areas of Flues and other Gas-passages.—Rules are sometimes given making the area of gas-passages bear a certain ratio to the area of the grate surface; thus a common rule for horizontal tubular boilers is to make the area over the bridge wall $\frac{1}{7}$ of the grate surface, the flue area $\frac{1}{8}$, and chimney area $\frac{1}{9}$.

For average conditions with anthracite coal and moderate draft, say a rate of combustion of 12 lbs. coal per square foot of grate per hour, and a ratio of heating to grate surface of 30 to 1, this rule is as good as any, but it is evident that if the draft were increased so as to cause a rate of combusion of 24 lbs., requiring the grate surface to be cut down to a ratio of 60 to 1, the areas of gas-passages should not be reduced in proportion. The amount of coal burned per hour being the same under the changed conditions, and there being no reason why the gases should travel at a higher velocity, the actual areas of the passages should remain as before, but the ratio of the area to the grate surface would in that case be doubled.

Mr. Barrus states that the highest efficiency with anthracite coal is obtained when the tube area is $\frac{1}{9}$ to $\frac{1}{10}$ of the grate surface, and with bituminous coal when it is $\frac{1}{6}$ to $\frac{1}{7}$, for the conditions of medium rates of combustion, such as 10 to 12 lbs. per square foot of grate per hour, and 12 square feet of heating surface allowed to the horse-power.

The tube area should be made large enough not to choke the draft, and so lessen the capacity of the boiler; if made too large the gases are apt to select the passages of least resistance and escape from them at a high velocity and high temperature.

This condition is very commonly found in horizontal tubular boilers where the gases go chiefly through the upper rows of tubes; sometimes also in vertical tubular boilers, where the gases are apt to pass most rapidly through the tubes nearest to the centre. It may to some extent be remedied by placing retarders in those tubes in which the gases travel the quickest.

Air-passages Through Grate-bars.—The usual practice is to make the air-opening equal to 30% to 50% of the area of the grate; the larger the better, to avoid stoppage of the air-supply by clinker; but, with coal free from clinker, much smaller air-space may be used without detriment. See "Grate-bars," in Chapter VII. page 202.

Performance of Boilers.—The performance of a steam-boiler comprises both its capacity for generating steam and its economy of fuel. Capacity depends upon size, both of grate surface and of heating surface, upon the kind of coal burned, upon the draft, and also upon the economy. Economy of fuel depends upon the completeness with which the coal is burned in the furnace, upon the proper regulation of the air-supply to the amount of coal burned, and upon the thoroughness with which the boiler absorbs the heat generated in the furnace. The absorption of heat depends upon the extent of heating surface in relation to the amount of coal burned or of water evaporated, upon the arrangement of the gas-passages, and upon the cleanness of the surfaces. The capacity of a boiler may increase with increase of economy when this is due to more thorough combustion of the coal or to better regulation of the air-supply, or it may increase at the expense of economy when the increased capacity is due to overdriving, causing an increased loss of heat in the chimney-gases. The relation of capacity to economy is therefore a complex one, depending on many variable conditions.

Many attempts have been made to construct a formula expressing the relation between capacity, rate of driving, or evaporation per square foot of heating surface, to the economy, or evaporation per pound of combustible; but none of them can be considered satisfactory, since they made the economy depend only on the rate of driving (a few so-called "constants," however, being introduced in some of them for different classes of boilers, kinds of fuel, or kind of draft), and

fail to take into consideration the numerous other conditions upon which economy depends. Such formulæ are Rankine's, Clark's, Emery's, Isherwood's, Carpenter's, and Hale's. A discussion of them all may be found in Mr. R. S. Hale's paper on "Efficiency of Boiler Heating Surface," in Trans. Am. Soc. M. E., vol. xviii. p. 328. Mr. Hale's formula takes into account the effect of radiation, which reduces the economy considerably when the rate of driving is less than 3 lbs. per square foot of heating surface per hour. The author's formula, in which the efficiency is shown to be a function of six different variables, the most important one being the air supply, is given in the chapter on Efficiency of Heating Surface. (Formulæ 13, 14, and 15, page 294.)

For figures of results obtained in tests see Chapter XVII.

CHAPTER XII.

"POINTS" OF A GOOD BOILER.

THE boilers which have been described and illustrated in Chapter X include all the types which are extensively used in land practice in the United States. They offer enough variety to satisfy the ideas or prejudices of all classes of purchasers. Boilers of each of these types, more or less modified, with one or two exceptions, are made by more than one builder, the fundamental patents on all of them having expired, and competition between rival builders is so intense that any kind of boiler may now be purchased at a slight advance over its cost to the builder. The factory cost has also been greatly reduced by the introduction of improved machinery and by the reduced prices of raw material. It would be out of place here to recommend any one type of boiler as superior to any other, but some ideas may be given in regard to the good and bad "points" of boilers in general, which may be of assistance to an intending purchaser or an engineer who is confused by the conflicting statements of rival builders or salesmen.

Selecting a New Type of Boiler.—The problem of selecting a new form of boiler to replace one of an old type is, to the average steam-user, one of considerable difficulty on account of the vast variety of styles that are now offered in the market, and the conflicting statements of rival builders. The evolution of the steam-boiler has now reached a period of extreme confusion, in which diversity of form is the leading feature. In land boilers we not only have the variety of styles shown in the table already given of percentages of different styles used in several countries of Europe, but in the United States there is a continual procession of new forms through the Patent Office, of which enough find builders and advertisers to continually add to the existing confusion.

The claims made for these new forms of boilers are generally in inverse ratio to their merits. The following are extracts from advertisements in a single issue of one trade journal in February, 1897:

No. 1.—We guarantee you a saving of from 10 to 25 per cent with

equal horse-power, or an increase of horse-power of from 10 to 25 per cent with the same fuel if you use the ——— steam-generator.

No. 2.—The circulation positively prevents scale.

No. 3.—The best boiler ever built, combining many points of merit not contained in any other boiler. Will evaporate the largest amount of water per pound of coal.

No. 4.—Is an efficiency of 30 per cent above all others of interest to you? Send for particulars.

No. 5.—An evaporation of 14.66 lbs. of water from and at 212° per pound of combustible.

Such extravagant claims for new forms of boilers are not now as common as they once were, but the following advertisement appeared in a trade journal in 1914.

Our boilers make less scale than boilers of any other make because they circulate the water more rapidly, heat it more uniformly and cause impurities to settle in the mud-drum while water is yet cool.

It is worthy of note that none of the large boiler companies, who have reputations established for many years, advertise in this manner, and of the boilers which are advertised in the above extracts, not one has any exceptional merit which would warrant its being selected in preference to the best of the older and better-known boilers. It is simply impossible that any one of these new boilers can, in an accurate test, evaporate 14.66 lbs. of water, from and at 212° per lb. of combustible (if coal is used as fuel, it might do this and more with petroleum), or that any one of them can show 10 per cent better economy than a well-proportioned boiler of older form, or that any kind of circulation can keep a boiler free from scale or from deposits of solid matter if the water contains scale-forming material.

The moral is this: Do not place any reliance in the advertisement of a boiler which claims that it is superior to all other boilers in fuel-economy or in prevention of scale. The largest and most successful boiler concerns, who make as good boilers as have ever been made, or are likely to be made for some years to come, do not advertise in this way.

Economy of Fuel.—Let it be assumed that all the boilers offered for choice are built by makers of good repute, that the quality of material and workmanship is beyond question, and that the dimensions and arrangement of all the parts are so chosen that they are all equally safe to resist a bursting pressure. These essentials of good boiler con-

struction may be secured with any of the types described, by having the specifications properly drawn and by rigid inspection of the material and workmanship. The economy of fuel which may be obtained with any boiler does not depend upon the type of boiler, but upon its proportions, such as the amount of heating and grate-surface furnished for a given horse-power, upon the kind of furnace used, and upon the arrangement of the gas-passages so as to cause the gas to give up as large a percentage of its heat as possible to the heating surface. These are matters of engineering design with any type of boiler, and any boiler may have them so arranged as to cause it to give as high an economy of fuel as is possible with any other boiler. Questions that arise under this head in regard to any boiler are: 1. Is the grate-surface sufficient for burning the maximum quantity of coal expected to be used at any time, taking into consideration the available draft, the quality of the coal, its percentage of ash, whether or not the ash tends to run into clinker, and the facilities, such as shaking grates, for getting rid of the ash or clinker? 2. Is the furnace of a kind adapted to burn the particular kind of coal used? 3. Is the heating surface of extent sufficient to absorb so much of the heat generated that the gases escaping into the chimney shall be reasonably low in temperature, say not over 500° F. with anthracite and 600° F. with bituminous coal? 4. Are the gas-passages so designed and arranged as to compel the gas to traverse at a uniform rate the whole of the heating surface, not being so large at any point as to allow the gas to find a path of least resistance or be short-circuited, or, on the other hand, so contracted at any point as to cause an obstruction to the draft?

These questions being settled in favor of any given boiler, and they may be answered favorably for boilers of any of the modern types already described, provided the furnaces and boilers are properly designed, the relative merits of the different types may now be considered with reference to their danger of explosion; their probable durability; the character and extent of repairs that may be needed from time to time, and the difficulty, delay, and expense that these may entail; the accessibility of every part of the boiler to inspection, internal and external; the facility for removal of mud and scale from every portion of the inner surface, and of dust and soot from the exterior; the water- and steam-capacity; the steadiness of water-level; and the arrangements for securing dry steam.

Each one of the points above referred to should be considered

carefully by the intending purchaser of any type of boiler with which he is not familiar by experience. The several points may be considered more in detail.

Danger of Explosion.—All boilers may be exploded by over-pressure, such as might be caused by the combination of an inattentive fireman and an inoperative safety-valve, or by corrosion weakening the boiler to such an extent as to make it unable to resist the regular working pressure; but some boilers are much more liable to explosion than others. In considering the probability of explosion of any boiler of recent design, it is well to study it to discover whether or not it has any of the features which are known to be dangerous in the plain cylinder, the horizontal tubular, the vertical tubular and the locomotive boilers. The plain cylinder boiler is liable to explosion from strains induced by its method of suspension, and by changes of temperature. Alternate expansion and contraction may produce a line of weakness in one of the rings, which may finally cause an explosion. A boiler should be so suspended that all its parts are free to change their position under changes of temperature without straining any part. The circulation of water in the boiler should be sufficient to keep all parts at nearly the same temperature. Cold feed-water should not be allowed to come in contact with the shell, as this will cause contraction and strain. The horizontal tubular boiler, and all externally-fired shell boilers, are liable to explosion from overheating of the shell, due to accumulation of mud, scale or grease on the portion of the shell lying directly over the fire; to a double thickness of iron, as at a lap-joint, together with some scale, over the fire; or to low water uncovering and exposing an unwetted part of the shell directly to the hot gases. Vertical tubular boilers are liable to explosion from deposits of mud, scale or grease upon the lower tube-sheet, and from low water allowing the upper part of the tubes to get hot and cease to act as stays to the upper tube-sheet. Locomotive boilers may explode from deposits on the crown-sheet, from low water exposing the dry crown-sheet to the hot gases, and from corrosion of the stay-bolts. Double-cylinder boilers, such as the French elephant boiler, and the boilers used at some American blast-furnaces, have exploded on account of the formation of a "steam-pocket" on the upper portion of the lower cylinder, the steam being prevented from escaping by the lap-joint of one of the rings, thus making a layer of steam about ¼ inch thick against the shell which was directly exposed to the hot gases.

The above-mentioned are only a few of the causes of explosions, but they are the principal ones that are due to features of design. These features should be looked for in any new style of boiler, and if they are found they should be considered elements of danger. Such questions as the following may be asked: Is the method of suspension of the boiler such as to allow its parts to be free to move under changes of temperature? Is the circulation such as to keep all parts at practically the same temperature? Is there a shell with riveted seams exposed to the fire? Is there a shell exposed to the fire which may at any time be uncovered by water or be covered with scale? Is there a crown-sheet on which scale may lodge? Are there sufficient facilities for the removal of scale? Are there vertical or inclined tubes acting as stays to an upper sheet, the upper part of which tubes may become overheated in case of low water? Are there any stayed sheets, the stays of which are liable to become corroded? Is there any chance for a steam-pocket to be formed on a sheet which is exposed to the fire?

In addition to the above-mentioned features of design, which are elements of danger, all boilers, as already stated, are liable to explosion due to corrosion. Internal corrosion is usually due to acid feed-water, or to very pure feed-water containing dissolved air, and all boilers are equally liable to it. External corrosion, however, is more liable to take place in some designs of boilers than in others, and in some locations rather than in others. If any portion of a boiler is in a cold and damp place, it is liable to rust out. For this reason the mud-drums of many modern forms of boilers are made of cast iron, which resists rusting better than either wrought iron or steel. If any part of a boiler, other than a part made of cast iron, is liable to be exposed to a cold and damp atmosphere, or covered with damp soot or ashes, or exposed to drip from rain or from leaky pipes, and especially if such part is hidden by brickwork or otherwise so that it cannot be inspected, that part is an element of danger.

Durability.—The question of durability is partly covered by that of danger of explosion, which has already been discussed, but it also is related to the question of incrustation or scale. The plates and tubes of a boiler may be destroyed by internal or external corrosion, but they may also be burned out. It may be regarded as impossible to burn a plate or tube of iron or steel, no matter how high the temperature of the flame, provided one side of the metal is covered with water. If a steam-pocket is formed, so that the water does not touch

the metal, of if there is a layer of grease or hard scale, then the plate or tube may be burned. In a water-tube which is horizontal, or nearly so, and in which the circulation of water is defective, it is possible to form a mass of steam which will drive the water away from the metal, and thus allow the tube to burn out. In considering the probable durability of a boiler, we may ask the same questions as those that have been asked concerning danger of explosion. There are, however, many chances of burning out a minor part of a boiler without serious danger, to one chance of a disastrous explosion. Thus the tubes of a water-tube boiler, if allowed to become thickly covered with scale, might be burned out without causing any further destruction than the rupture of a single tube. A new type of boiler should be questioned in regard to the likelihood of frequent small repairs being necessary, and as well in regard to its liability to complete destruction. We may ask: Is the circulation through all parts of the boiler such that the water cannot be driven out of any tube or from any portion of a plate, so as to form a steam-pocket exposed to high temperature? Are there proper facilities for removing the scale from every portion of the plates and tubes?

Repairs.—The questions of durability and of repairs are, in some respects, related to each other. The more infrequent and the less extensive the repairs, the greater the durability. The tubes of a boiler, where corroded or burnt out, may be replaced, and made as good as new. The shell, when it springs a leak, may be patched, and is then likely to be far from as good as new. When the shell corrodes badly it must be replaced, and to replace the shell is the same as getting a new boiler. Herein is one advantage of the sectional water-tube boilers. The sections, or parts of a section, may be renewed easily, and made good as new, while the shell, being far removed from the fire and easily kept dry externally, is not liable either to burning out or external corrosion. In considering the merits of a new style of boiler, with reference to repairs, we may ask what parts of the boiler are most likely to give out and need to be repaired or replaced? Are these repairs easily effected; how long will they require; and after they are made is the boiler as good as new? If a new style of boiler made up of special parts not procurable except from its builder, the question may be asked: How long is the builder likely to remain in business and be able to furnish these special parts?

Facility for Removal of Scale and for Inspection.—These questions have already been discussed to some extent under the head of dura-

bility. Some water-tube boilers, now dead and gone, were some years ago put on the market, which had no facilities for the removal of scale. It was claimed by their promoters that they did not need any, because their circulation was so rapid. Every few years boilers of these types are re-invented, and the same claim is made for them, that their rapid circulation prevents the formation of scale. The fact is that if there is scale-forming material in the water it will be deposited when the water is evaporated, and no amount or kind or circulation will keep it from accumulating on every part of the boiler and in every kind of tubes, vertical, horizontal, and inclined. The nearly vertical circulating tubes of a water-tube boiler, in which the circulation is nine times as fast as the average circulation in the inclined tubes, sometimes have been found nearly full of scale; that is, a 4-inch tube had an opening in it of less than 1 inch diameter. This was due to carelessness in blowing off the boiler, or exceptionally bad feed-water, or both. If circulation would prevent scaling at all, it would prevent it here.

Water- and Steam-capacity.—It is claimed for some forms of boilers that they are better than others because they have a larger water- or steam-capacity. Great water-capacity is useful where the demands for steam are extremely fluctuating, as in a rolling-mill or a sugar refinery, where it is desirable to store up heat in the water in the boilers during the periods of the least demand, to be given out during periods of greatest demand. Large water-capacity is objectionable in boilers for factories, usually, especially if they do not run at night, and the boilers are cooled down, because there is a large quantity of water to be heated before starting each morning. If "rapid steaming" or the ability to get up steam quickly from cold water, or to raise the pressure quickly, is desired, large water-capacity is a detriment. The advantage of large steam-capacity is usually overrated. It is useful to enable the steam to be drained from water before it escapes into the steam-pipe, but the same result can be effected by means of a dry pipe, as in locomotive and marine practice, in which the steam-space in the boiler is very small in proportion to the horse-power. Large steam-space in the boiler is of no importance for storing energy or equalizing the pressure during the stroke of an engine. The water in the boiler is the place to store heat, and if the steam-pipe leading to an engine is of such small capacity that it reduces the pressure at the engine, the remedy is a steam-reservoir close to the engine or a large steam-pipe.

Water Space and Steam Space.—The sizes of the water space and the steam space of a steam boiler have no necessary relation to either its capacity or its economy. A small water space will cause a boiler to be a "rapid steamer;" that is, it will generate steam in a short time after a fire is started in the furnace, and rate of generation of steam will vary with every change of condition of the fire and of the draft. Steam fire-engines have boilers with very small water spaces. Large water spaces act as reservoirs of heat, and they tend to cause the boiler to steam steadily, although the conditions of the fire may vary. They are of special value when the engine load is a fluctuating one, as in rolling-mills, electric street railway service, etc.

The extent of steam space is rather an accident of the shape of the boiler than an element in its design. A study of the amount of steam space per rated horse-power in different styles of boilers, by S. Q. Hayes (*Power,* Sept., 1894), gives the following figures: Locomotive, 0.141 sq. ft.; Harrison safety, 0.196; vertical tubular, 0.320 to 0.665; water tube safety, 0.336 to 0.906; horizontal return tubular, 0.752 to 0.985; two-flue, 1.51 to 1.92; and plain cylindrical boilers, 2.50 sq. ft.

Steadiness of Water-level.—This requires either a large area of water-surface and volume of water, so that the level may be changed slowly by fluctuations in the demand for steam or in the delivery of the feed-pump, or else constant, and preferably automatic, regulation of the feed-water supply to suit the steam demand. A rapidly lowering water-level is apt to expose dry sheets or tubes to the action of the hot gases, and thus be a source of danger. A rapidly rising level may, before it is seen by the fireman, cause water to be carried over into the steam-pipe, and endanger the engine.

Large area of water-surface alone is not always sufficient to insure steadiness of water-level. Sudden fluctuations in the activity of the fire, such as take place when the gases from freshly-fired soft coal burst into flame, are apt to cause a sudden rise in the water-level. For this reason, boilers with horizontal water- and steam-drums, whether fire-tube or water-tube boilers, should preferably have drums not less than 30 ins. diameter, so that the water-level may be allowed to vary 5 or 6 ins. from its normal position without, on the one hand, endangering the burning out of the tubes, or, on the other, of making wet steam.

Dryness of Steam.—Most of the modern forms of both fire-tube and water-tube boilers give practically dry steam, that is, steam con-

taining not over $1\frac{1}{2}\%$ of moisture, when the water-level is not allowed to rise more than 5 or 6 ins. above its mean position, even when driven as much as 100% beyond their rated capacity; but boilers with vertical tubes, with small water-level area, are apt, sometimes, to have the water-level fluctuate violently, and they require to be provided with superheating surface and dry pipes, or steam separators, in order to insure dry steam. Alkaline feed-water is often a cause of "foaming," causing wet steam.

Water-circulation.—Positive and complete circulation of the water in a boiler is important for two reasons: (1) To keep all parts of the boiler of a uniform temperature, and (2) to prevent the adhesion of steam-bubbles to the surface, which may cause overheating of the metal. It is claimed by some manufacturers that the rapid circulation of water in their boilers tends to make them more economical than others. We have as yet, however, to find any proof that increased rapidity of circulation of water beyond that usually found in any boiler will give increased economy. We know that increased rate of flow of air over radiating surfaces increases the amount of heat transmitted through the surface, but this is because by the increased circulation cold air is continually brought in contact with the surface, making an increased difference of temperature on the two sides, which causes increased transmission. But by increasing the rapidity of circulation in a steam-boiler we cannot vary the difference of temperature to any appreciable extent, for the water and the steam in the boiler are at about the same temperature throughout. The ordinary or "Scotch" form of marine boiler shows an exception to the general rule of uniformity of temperature of water throughout the boiler, but the temperature above the level of the lower fire-tubes is practically uniform.

CHAPTER XIII

BOILER DESIGN AND CONSTRUCTION.

Boiler and Boiler Plant Design.—Steam-boiler design may be divided into two parts: 1, general or plant design, that is the determination of the kind, number, size and arrangement of boilers required to produce a given amount of steam in a stated time, the total area of grate surface, the kind of furnace or stoker to be used; and, 2, detail design, relating to the construction of an individual boiler after its general shape and size have been determined.

The consulting engineer or the engineer of a power plant is usually concerned only with the first of these two branches of the general subject of boiler design; he leaves to the engineer of the boiler maker the details of the manufacture of the boiler itself, except in so far as he compares the specifications offered by each boiler maker with the requirements named in his general specifications and with governmental rules and regulations and the rules of boiler insurance companies. Occasionally a consulting engineer is called on to make an original design of a boiler, but not often; the usual rule is to accept the standard design of boilers that are in the market.

In preparing to make a design for a boiler plant for any given service the following data should be known, at least approximately:

a. The nature of the demand for steam, whether steady or fluctuating.

1. If steady, as in a cotton mill, the number of pounds of water to be evaporated per hour when the mill is running at its full capacity.
2. If fluctuating, as in an electric power and lighting plant, or a central station heating plant, charts showing the steam demand for each hour of a day in seasons of heaviest and of lightest demand.

b. The quality and price of coal or other fuel.

c. The quality of the feed water.

d. The temperature of the feed water.

e. The maximum pressure of steam to be carried.

From the data d and e the factor of evaporation is calculated, which, multiplied by the pounds of water per hour, from data a, 1 and 2, gives the equivalent evaporation per hour from and at 212°.

For a steady demand, as in 1, it will usually be found most profitable to install sufficient heating surface so that the boilers will not have to be driven at a rate higher than their normal rating of 10 sq. ft. of heating surface per boiler horse-power, or 3.45 lbs. of water evaporated from and at 212° per sq. ft. of heating surface per hour.

With loads that have a high peak, lasting but 4 to 8 hours out of the 24, as in 2, a great saving in first cost of boilers and of real estate may be made by allowing the boilers to be driven during the peak of the load at from 2 to 3 times their normal rating, but in that case it will be necessary both to install mechanical stokers and to control the firing by analyses of the gases, in order to avoid excessive waste of fuel by overdriving, such as is shown by the diagrams of efficiency given in Chapter IX.

In all cases provision must be made for one, or in large power plants more than one, of the boilers to be out of service for cleaning or repairs.

Having determined the amount of heating surface required the next question to be settled is the amount of grate surface. This depends on several considerations:

1. The cost of real estate. If it is very costly, as in large cities, it may be advisable to use relatively small grate surface and to burn the coal at a high rate during the heavy load, say 25 to 50 lbs. of coal per sq. ft. of grate surface per hour, but this requires special facilities for getting rid of ash and clinker, such as shaking grates or mechanical stokers, very large combustion chambers, to allow of the gases being burned before they reach the heating surfaces, and high chimneys, 150 ft. or over, or forced draft. In some large plants it has been found advisable, on account of the expense of ground space to locate the boilers on two or three floors of the boiler house. Where real estate is not expensive it is desirable to proportion the grate surface liberally, so as to require the burning of say from 10 to 20 lbs. of coal per sq. ft. of grate per hour, especially for small plants with moderate heights of chimney and hand firing.

2. The quality and price of fuel that is available. These will govern to a large extent the size of the grate surface and the volume of combustion space to be provided. With Western bituminous coals and lignites, and wood, bagasse, tan bark and the like, the grate sur-

face and the combustion chamber require to be much larger than with semi-bituminous or Eastern bituminous coals. With anthracite of small size, high in ash, very large grate surfaces are needed, but on account of the small proportion of volatile matter large combustion chambers are not necessary. With oil fuel no grate surface is needed, but the combustion chamber must be large for high rates of driving, in order that the fuel may be burned without smoke and with good economy.

The total amount of heating surface and grate surface having been decided upon, a selection of the type of boiler suitable for all the conditions, including the kind of feed-water, may now be made from the various types in the market, after a careful consideration of the "Points of a Good Boiler" described in Chapter XII, and general specifications may now be sent to the most reliable manufacturers asking for bids and detailed specifications for boilers of the total heating surface and grate surface required, the boilers to carry the maximum stated pressure with a factor of safety of not less than 5, and to occupy not more than the total ground area of the size and shape given, including in this area sufficient room for passages between batteries or groups of boilers, for firing space, for storage of a given quantity of coal, and space for removal of tubes and for access to the rear of the boilers.

The size of the individual boilers in a plant requires some consideration. For many years boilers of 500 to 600 H.P. (5000 to 6000 sq. ft. of heating surface) have been most common in large plants, but there is a tendency to use much larger boilers, 1000 to 2000 H.P. and upwards, the advantages being a saving in ground space and in brick-work, and a possible saving of fuel due to more perfect control of furnace conditions by analyses of the gases and of labor, due to there being fewer furnaces to be attended to. With these large boilers automatic feeding of coal from overhead storage bins is essential.

Modern Boiler Plants.—In the most recent large power plants no expense has been spared in the installation of machinery to handle both coal and ashes, thereby reducing the labor cost, and also to provide very large combustion spaces, to enable the volatile gases to be completely burned before they reach the heating surface of the boilers even at the maximum rate of driving. In consequence a cross-sectional view through the boiler house shows that the greater portion of its space is taken for coal- and ash-storage, for room for railroad cars to

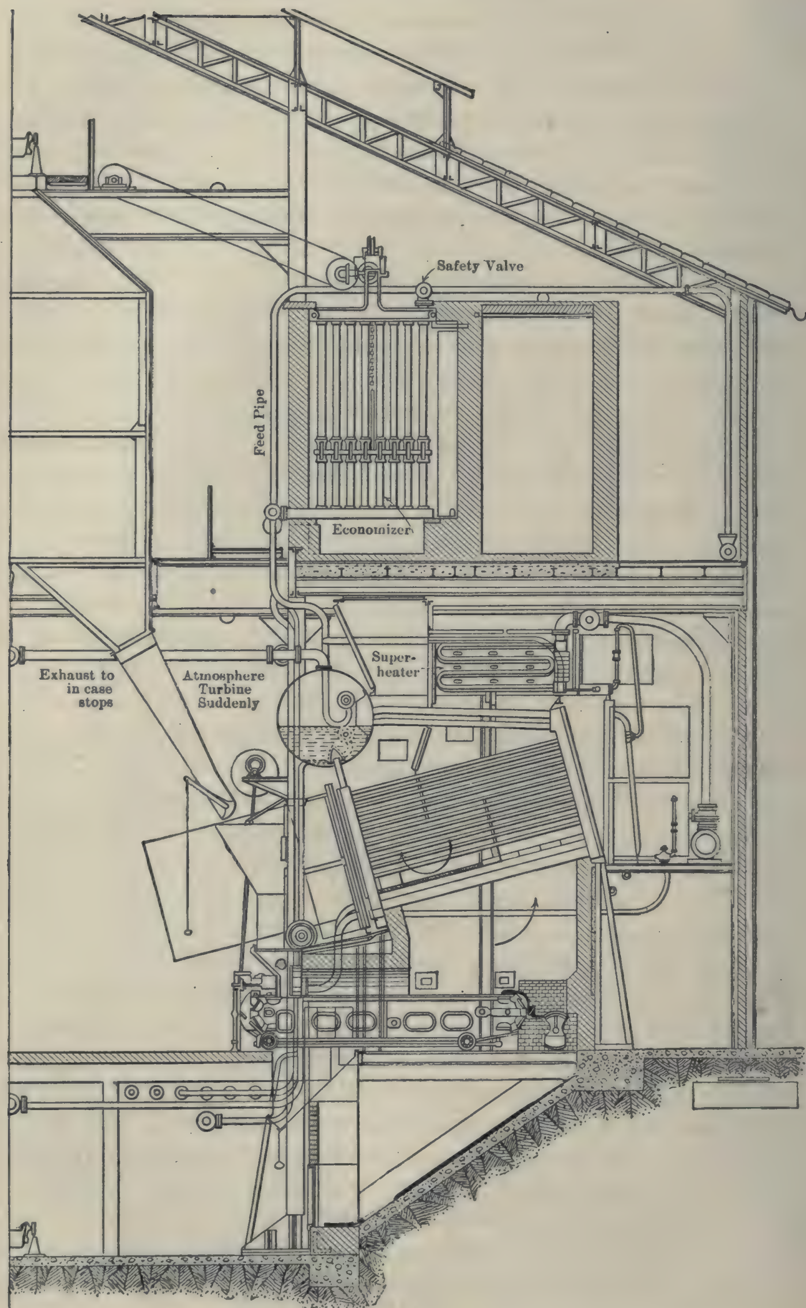

FIG. 141.—SECTION THROUGH ONE-HALF OF A LARGE BOILER PLANT.

deliver coal and receive ash, elevators for handling the material, and for combustion spaces, flues and chimney. Illustrations of two boiler plants showing these features are shown below.

A Large Boiler Plant in France.—*Power,* Jan. 31, 1911, describes the St. Denis station of the Electrical Society of Paris. Fig. 141 shows a section through one-half of the boiler house. The boilers, 17 in all, are of the marine Babcock & Wilcox type, provided with very long chain-grate stokers, the front half of which are roofed over, large combustion chambers, superheaters and Green economizers. It will be noticed that in this, as in all large modern power plants the space occupied by the boilers themselves is but a small fraction of the total space in the boiler house. Each boiler has 4520 sq. ft. of heating surface, 147 sq. ft. grate surface; ratio 30.8 to 1; 1215 sq. ft. superheater surface and 1600 sq. ft. economizer surface. The boilers are guaranteed to deliver 4 lbs. of steam, superheated to 662°F., per sq. ft. of heating surface per hour, with capacity for 25% increase, or 5 lbs., without difficulty, with an efficiency of 80%, including the economizers, when evaporating at the rate of 3.7 to 3.9 lbs. of steam per hour per sq. ft. of boiler surface, at 662° F., the feed-water temperature being 68° F. This evaporation, taking the higher figures, is equivalent to 5 lbs. from and at 212° per sq. ft. of boiler heating surface per hour. An 8-hour test of 5 boilers made in 1908, with Scotch coal containing by analysis 33.6 volatile matter, 7.6 moisture, 7.3 ash, gave an equivalent evaporation from and at 212° of 5.93 lbs. per sq. ft. of heating surface per hour, and an efficiency of 83.3%, including the economizer. Some of the other data are as follows:

	Deg. F.	B.T.U. above 32°.	Diff.
Temperature of water entering economizer..	105.8	73.7	
" " " leaving economizer...	200.1	168.0	94
" " steam entering superheater.	381.2	1198	1030
" " " leaving superheater..	579.2	1307	109
" " gases entering economizer..	534.2		
" " " leaving economizer...	327.2		
Steam pressure 185 lbs. gage. CO_2 in gases.	12%		

The efficiency of the boiler and superheater, omitting the economizer was $83.3 \times 1139 \div 1233 = 77\%$. The gain due to the economizer was $94 \div 1139 = 7.6\%$.

The Northwest Station of the Commonwealth Edison Co., Chicago. (*Power,* April 29, 1913).—The plans provide for two separate groups of buildings, as a precaution against complete interruption of service by an accident, each group consisting of a generator house, a boiler house, and a low building containing transformers, bus bars, and switches. Each generator house is planned for six 20,000 KW. Curtis turbine generators, and each turbine is served

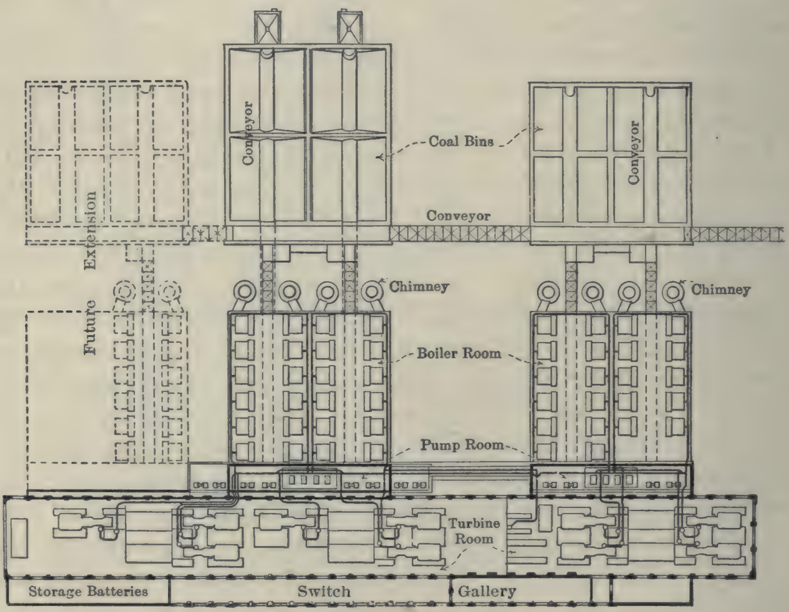

FIG. 142.—PLAN OF LARGE ELECTRIC POWER PLANT.

by its own group of 10 boilers, each of 5800 sq. ft. of heating surface and capable of generating economically 30,000 lbs. of steam per hour. Each group of boilers is ample to supply its generator under maximum load, allowing one boiler to be out of service for cleaning or repairs. Fig. 143 shows a cross section through one of the groups of 10 boilers and through the coal-handling space serving two opposite groups.

The boilers are set with a high combustion chamber. The coal is burned on Babcock & Wilcox chain grates, which have an area of 115 sq. ft., giving a ratio of grate surface to heating surface of 1 to 50.4. Steam is generated at 250 lbs. pressure and superheated

125° F. Each group of boilers is served by its own steel stack, 250 ft. high, above the boiler-room floor, by 17 ft. inside diameter.

A separate coal-handling system is employed for each two groups of boilers. Coal either direct from the mine or from storage piles is run into the boiler house in cars at grade level underneath the fire-room floor, which is some 22 ft. above the ground line. The two tracks bring the cars over a reinforced-concrete hopper and thus the dumping type of car can be unloaded into the hopper direct. The non-dumping cars are unloaded by a traveling crane and a 2-cu. yd. clam-shell bucket which drops the coal through an opening provided between the tracks. From the receiving hopper the coal is fed into a traveling crusher which runs on tracks over the 34x36-in. buckets of a conveyor. The conveyor raises the coal and deposits it in overhead bunkers located over the firing aisle, as shown, and from these it is fed through spouts to the stoker hoppers.

The fine coal which sifts through the grates falls through spouts back into the receiving hopper and is again raised to the overhead bunkers by the conveyor. The ashes falling off the end of the chain grates are caught in ash hoppers below, which have a capacity for one day's accumulation. Railroad cars for receiving the ashes are run in under the hoppers and the latter are emptied once each day.

Designing Boilers for a Small Street-railway Plant.*—In entering upon the studies preliminary to the design of the steam-boilers for a small or medium-sized electrical street-railway power-plant the engineer must take into consideration some peculiar features of the service required from the boilers which differ more or less from those which govern the design of boilers for other purposes, such as a factory. Such features are: the extreme variations of the load upon the engines from hour to hour, and the consequent variation in the quantity of steam to be furnished; the prime necessity of having the boiler-plant constantly in condition to furnish the maximum amount of steam required during the hours of heaviest load; the absence of holidays or slack seasons during which general repairs or alterations may be made; and the considerable uncertainty that exists before the plant is put in operation concerning the actual amount of power that may be required and the probable additions that may be needed as the road is extended or as traffic increases. The first considerations, therefore, in the design of the boiler-plant are certainty of operation under the severest load, and capacity for furnishing the maximum amount of steam that may be needed under the most adverse conditions, such as a combination of heaviest load, bad weather, poor

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* From an article by the author in *Street Railway Review*, February, 1899.

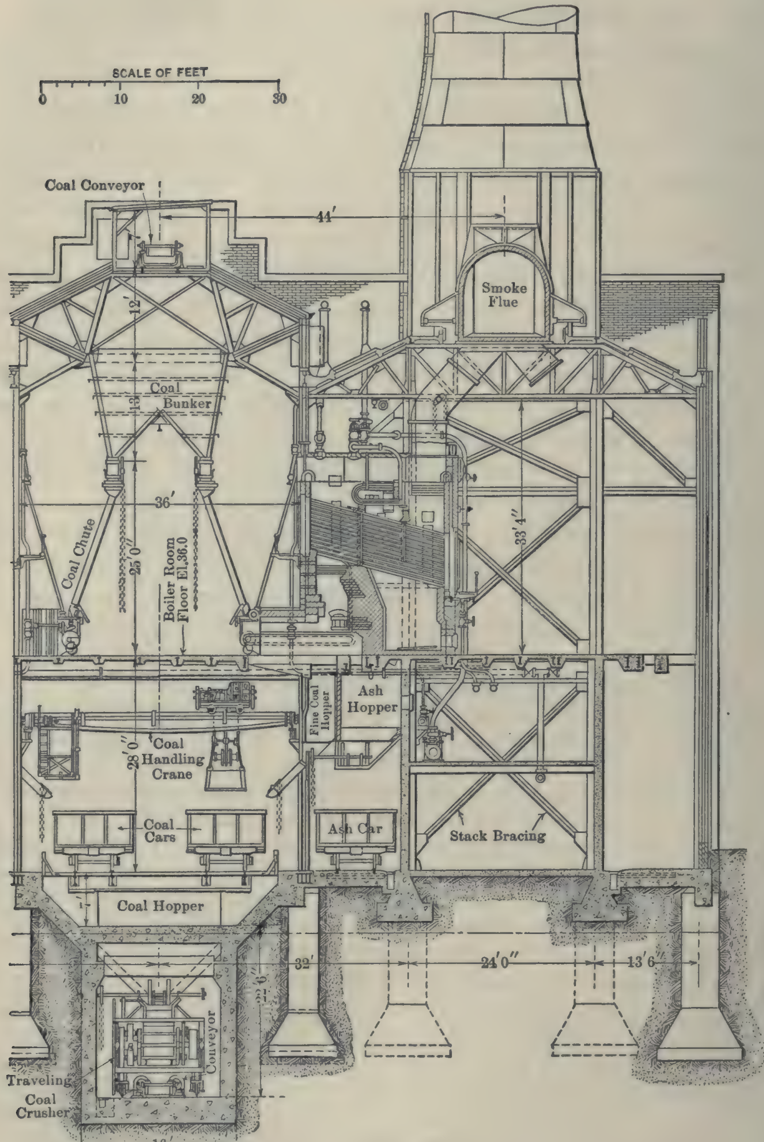

Fig. 143.—Boiler Plant of Commonwealth Edison Co., Chicago.

coal, and a portion of the boiler-plant being laid off for cleaning or repairs.

To meet these requirements it is necessary not only to have the boilers of sufficient capacity to meet the greatest demand for steam, but also to have enough boilers to allow one of them to be laid off without curtailing the steam-supply below the maximum quantity that may at any time be required by the engines. In even the smallest-sized plant it is advisable to have not less than three boilers, any two of which are able to run the plant at the time of heaviest loading. In larger plants, four, five, or more boilers may be installed, and so arranged that any one of them may be laid off at any time for

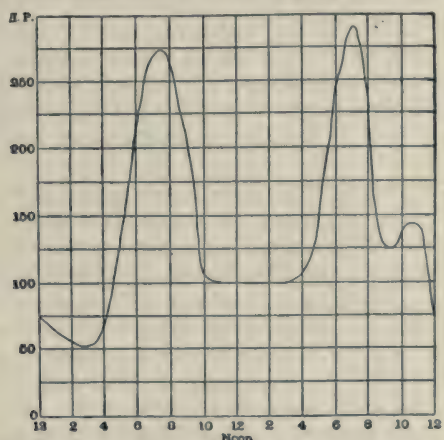

FIG. 144.—LOAD-DIAGRAM OF A STREET-RAILWAY PLANT.

cleaning or repairs without interfering with the operation of the others.

Assuming that the boiler-plant is to contain one boiler more than is sufficient to generate the steam required under the conditions of maximum load, the poorest coal being supplied that is ever expected to be used at the station, and the weather the most unfavorable as regards the draft and the amount of moisture in the air and in the coal, we proceed to consider the number, size, proportions, and style of the boilers to be selected.

The boiler-plant is usually one of the last of the divisions of the complete power-plant that are to be designed. Before designing it we must know the maximum quantity of steam that will be needed. The electrical engineer of the railway company will furnish data as to the electrical horse-power that will be required from the dynamos; and he will hand to the steam engineer a diagram something like the one shown in the accompanying cut, Fig. 144, giving the heaviest loads expected on the dynamos during twenty-four hours. From these data the steam-engines or turbines will be selected, involving

a study of their size and of their probable steam-consumption at different loads. The two "peaks" of the load-diagram will be carefully considered, and the question will be decided whether these peaks are to be taken care of by storage-batteries, by overloading the engines or dynamos, or by the use of a separate engine and dynamo to be operated during three or four hours of the day when the load is heaviest.

The steam-engine questions being decided, a careful calculation is then made of the probable steam consumption per hour during the single hour or fraction of an hour of maximum load. Not until this question is settled is it time to prepare the design of the boiler-plant.

The boilers, after one of them is reserved for cleaning or repairs, must be capable of furnishing sufficient steam to the engines during the time of the peak of the load, even when the coal is poor and the weather bad, and the engine not in its best condition as to steam-tightness and valve-adjustment; and to this consideration every other one, such as first cost of boilers, or economy of coal, must be made secondary.

The maximum number of pounds of steam per hour now being given, and the pressure of steam required by the engines and the probable feed-water temperature being known, we have the data with which to begin figuring on the boilers. By referring to a table of "factors of evaporation," we may reduce this number to the equivalent number of pounds per hour evaporated "from and at 212° F." Dividing this by 34½ gives the number of "boiler horse-power." A slight allowance, say 1 per cent, may be added to cover loss of heat due to radiation from the steam-pipes.

Having the amount of work to be done by the boilers during the time of the peak of the load, we now consider how this capacity is to be obtained. The first essential in a boiler is a furnace with capacity for burning enough coal. We must therefore proportion the furnace before we proportion the boiler, and to do this we must first find out how many pounds of coal are to be burned per hour during the time of maximum steam demand. This is rather a complex question, for it involves many variable elements, such as the quality of the coal, the kind of furnace, the rate of driving of the boiler, and the skill of the firemen.

The number of pounds of coal required per hour will be equal to the quotient obtained by dividing the equivalent evaporation from and at 212° per hour, in pounds, by the number of pounds of water that may be evaporated from and at 212° by 1 lb. of coal. This latter number will vary anywhere from 12, when the best grade of semi-bituminous coal, low in ash, is used, in a furnace adapted to burn all the volatile part of the coal, with a boiler so proportioned as to be capable of absorbing 75 per cent of the heat generated in the furnace, and with skilful firing, down to 5 lbs. or less, with a poor grade of western bituminous coal, high in moisture, ash, and sulphur, burned

in an ordinary furnace directly under the boiler, with no provision for burning the volatile matter or preventing smoke, with a boiler having insufficient heating surface, and therefore overdriven, and with unskilful firing. With lignite, or lignitic coal, from Utah, a figure as low as 3.79 lbs. has been obtained. (Trans. A. S. M. E., vol. iv. p. 263). The writer once obtained as low as 5.09 lbs. from a poor quality of Illinois coal, with expert firing, with the boiler driven 16 per cent below its rating, but with both the furnace and the grate-bars unsuited to the coal. (Trans. A. S. M. E., vol. iv. p. 267.)

It may be estimated that with any kind of coal the evaporation per pound of coal will be in the neighborhood of 15 per cent less with a rate of driving of 6 lbs. of water from and at 212° per square foot of heating surface per hour than at a rate of 3 lbs., the rate for maximum economy. [This is for hand-fired boilers in ordinary operation, With mechanical stokers and the firing regulated in accordance with the results of gas analyses the loss due to driving at the higher rate may be reduced to 6 or 7 per cent.]

Extent of Heating Surface Required.—For factory boilers, or for any boilers that are to be driven at a uniform rate throughout the day, the boilers should be so proportioned that the rate of driving should not exceed 3 lbs. of water from and at 212° per square foot of heating surface per hour; the extra cost of coal for driving at a more rapid rate usually being greater than the interest on the extra investment necessary to secure a sufficient extent of heating surface over and above that required for more rapid rates of driving.

With boilers for electric street-railway service, however, the case is entirely different. The heavy load upon the boiler-plant lasts for only about four hours out of the twenty-four, and unless money is very cheap and coal very dear, it will usually pay to sacrifice say 15 per cent of economy during those four hours rather than go to the expense necessary to proportion the boilers so that they will be driven at their most economical rate during those four hours. It is also to be considered that the extra boiler which is to be put in the plant so that any one boiler may at any time be laid off for cleaning or repairs may be used most of the time, since repairs and cleaning are not required often, so that all the boilers may be in service during the time of the peak of the load for a large proportion of the days of the year, and the excessive rate of driving during the time of the peak of the load may thus be diminished.

It will therefore not be bad designing if the extent of heating surface is proportioned so as to allow of the boilers, after one is laid off for cleaning or repairs, to be driven at a rate of 6 lbs. of water evaporated from and at 212° per square foot of heating surface per hour during the time of the peak of the load, and sufficient coal-burning capacity is provided in the furnaces, so that enough coal may be burned, including the 15 per cent wasted by rapid driving, to evaporate this amount under the most unfavorable conditions of wet

weather and of poor coal. [In the most modern practice with underfeed stokers, boilers are sometimes driven during peak loads at a rate as high as 10 lbs. of water from and at 212° per sq. ft. per hour.]

Assume that the steam engineer's estimates show that 600 I.H.P. will be required to be furnished by the engines during the time of maximum load, that the engines are non-condensing, requiring 30 lbs. of steam per I.H.P. per hour at their economical load and 20 per cent more when overloaded so as to furnish the 600 I.H.P.; that the feed-water is furnished from a heater at 200° F., and that the steam-pressure is 125 lbs., we then make a calculation as follows:

	600	I.H.P.
	30	lbs. steam per I.H.P. per hour.
	18,000	lbs. per hour.
Add.......	3,600	20 per cent for overloaded engines.
	21,600	lbs. per hour.
Mult. by...	1.056	factor of evaporation for feed at 200° and steam of 125 lbs.
Product ...	22,810	lbs. equivalent evaporation from and at 212° per hour.
Divide by..	6	lbs. evaporation per square foot heating surface per hour.
Quotient...	3,802	square feet heating surface.

This is the very smallest amount of heating surface that should be provided for the given conditions. It may be divided among two boilers of not less than 1901 sq. ft. each, or three boilers of 1267 sq. ft. each, and in either case an additional boiler of the same size must be provided so that one boiler may be laid off. The plant will therefore contain either three boilers of 1901 sq. ft. each = 5703 sq. ft., or four boilers of 1267 sq. ft. each = 5068 sq. ft. It may be found that the three larger boilers including setting, valves, piping, etc., will cost little if any more than the four smaller boilers with their setting, etc., and it may also be considered advisable to have the three larger boilers, with their greater total extent of heating surface, to provide against the contingency of an increased amount of steam being needed by the engines.

A plant of three boilers is a favorite arrangement for a new street-railway plant, two of the boilers being set in one battery and the third singly, a space being left alongside of the third boiler for a fourth, completing two batteries, if ever it should be needed.

Now let us assume that the coal to be used is a rather low grade of Illinois coal, of a heating value of 14,300 heat-units per pound of combustible, and that it may be expected to contain occasionally as high as 18 per cent ash and 12 per cent moisture. The heating value per pound of coal will then be $14,300 \times 0.70 = 10,010$ heat-units. This divided by 970.4 gives 10.32 lbs. of water from and at 212° as the possible evaporation of the coal if it were completely burned and all the heat utilized by the boiler. But only a portion can be utilized,

say 55 per cent, if the boiler is provided only with an ordinary setting, or say 65 per cent if it is set with a fire-brick oven, especially designed to burn the volatile gases, or if it is provided with a down-draft furnace or a mechanical stoker suitable for that grade of coal. The difference in economy between an efficiency of 55 per cent and one of 65 per cent is not 10 per cent, as some may suppose, but $10 \div 65 = 15.4$ per cent.

We now make the following calculation:

	Plain Furnace.	Special Furnace.
Heating value of 1 lb. of coal, equivalent evaporation from and at 212°	10.32	10.32
Efficiency of boiler and furnace	.55	.65
Product, lbs. from and at 212°	5.676	6.708
Deduct 15 per cent for loss due to driving the boiler at 6 lbs. per sq. ft. of heating surface per hour, or double its most economical rate	851	1.006
Lbs. water evaporated from and at 212° per lb. of coal	4.825	5.702
Divide these figures into the figure already found for total water from and at 212° per hour	22,810	22,810
Quotient, lbs. of coal per hour	4,727	4,000

The difference, 727 lbs., is 15.4 per cent of 4727 lbs., which agrees with the economy of the more efficient furnace as above stated and checks the computation.

Extent of Grate-surface Required.—To calculate the extent of grate-surface required we must know how many pounds of coal may be burned per square foot of grate per hour. This will depend on the draft, on the kind of grate used, and on the nature of the coal as to free-burning quality and as to its clinkering on the grates and choking the air-supply. We may assume that a chimney 150 ft. high is provided, which after making allowances for bends in the flues from the boiler to the chimney will, under the most unfavorable conditions of weather, give a draft of at least 0.5 in. of water-column at the end of the boiler. The coal is free-burning, and will burn rapidly if supplied with enough air through the grate-bars, but it clinkers badly. With ordinary grates we cannot count on burning it at a faster rate than 25 lbs. per sq. ft. of grate per hour, but with shaking grates well handled, so as to keep the fire clear of clinker, a rate of 35 lbs. may be expected. We now calculate the grate-surface required as follows:

	Plain Furnace.	Special. Furnace.
Coal to be burned per hour, lbs	4727	4000
Plain grates, 25 lbs. per hour, sq. ft.	190	160
Shaking grates, 35 lbs. per hour, sq. ft.	135	114

With shaking grates and hard, steady firing, we may expect a loss through the grates of unburned coal amounting to about 2 per cent more than the loss through the plain grates, but as in a street-railway plant this hard firing will last only about two hours a day, we need make no change in our calculation on this account.

We thus have four different figures for the extent of grate-surface required, according to whether we use ordinary or special furnaces and ordinary or shaking grates. Dividing the heating surface already found, 3802, by these figures, we have for the ratio of heating to grate-surface the following:

	Plain Furnace.		Special Furnace.	
	Plain Grate.	Shaking Grate.	Plain Grate.	Shaking Grate.
Sq. ft. of grate	190	135	160	114
Ratio heating to grate-surface	20.1	28.2	23.8	33.3

These figures for the ratio of heating to grate-surface are very much smaller than those provided in the common designs of modern boilers, especially those of the water-tube type. The ratio they give usually ranges from 35 to 50. The reason for this difference is that the data upon which the above calculations are based are very different from those upon which these boilers are designed. We have assumed a maximum rate of driving of 6 lbs. of water evaporated from and at 212° per square foot of heating surface per hour, with an intentional sacrifice of economy in order to save first cost of installation. We have also assumed a low grade of coal that clinkers on the grate, and in the case of the plain furnace a low efficiency. In the design of the ordinary water-tube boiler, especially for factory purposes, economy of coal is the first consideration. The heating surface is therefore made of such an extent that it does not require to be driven at a rate greater than 3 lbs. per sq. ft. per hour on an average, with a maximum of 4 or 4½ lbs. The boilers are by most builders rated in H.P. at the rate of 3.45 lbs. evaporation per square foot of heating surface per hour, or 10 sq. ft. per H.P., and when evaporation tests are made to prove guarantees a good quality of coal is usually obtained and the boilers are driven at not above 4 lbs. per sq. ft. of heating surface per hour.

Another reason for the high ratios of heating to grate-surface in modern water-tube boilers is that when designed with a view to economy of first cost and of ground-space occupied they are made long, narrow, and high, so as to pile a great amount of heating surface on a small ground area. A narrow boiler means a narrow grate-surface, and as it is not easy for a fireman to handle with good results a grate over 7 ft. long, it means limited extent of grate-surface. This is all right for good semi-bituminous coal or for Pittsburg or Hocking

Valley bituminous, which are both free-burning and low in ash. With these coals and strong draft and a ratio of heating to grate-surface of 45 or even 50 to 1, it is possible to drive the boiler to double its economical rate. For poor coals, however, whether anthracite or bituminous, such a ratio gives entirely too small a grate for rapid driving.

In the year 1896, in a series of tests made by the writer on a water-tube boiler with a very poor quality of Illinois coal, with an ordinary furnace and plain grate-bars, and with a good draft, he found that only about 85 per cent of the capacity of the boiler could be developed even with expert firing. The chief troubles were the clinkering of the grates and the excessive amount of moisture in the coal, which retarded the combustion. With the same boiler provided with a fire-brick arch setting, with shaking grates, and with Hocking Valley lump coal the boiler was driven to over 170 per cent of its rating, or over 5.1 lbs. of water evaporated from and at 212° per square foot of heating surface per hour. Had it been possible to double the extent of grate-surface when using the poor grade of coal it is quite likely that the capacity obtained could have been doubled.

Having made the calculation, as above shown, for the extent of grate-surface required under the four assumed conditions, we must next consider which one of the four results should be adopted in the design. Unless coal is very cheap it will pay to go to any reasonable expense to provide the special furnace, either a fire-brick oven built in front of the boiler with arrangements for burning the smoky gases, or a down-draft furnace, or a mechanical stoker. .With any of these devices a saving of 15 per cent in fuel should be expected when the coal is a highly volatile bituminous. Shaking grates are also desirable in a street-railway plant using poor fuel, since they enable the grate to be kept free from clinker, and diminish greatly the grate-surface and therefore the ground area required.

Specifications for Bids.—Having fixed upon the extent of grate-surface that is necessary to burn the coal under the most unfavorable conditions of weather, moisture, etc., for the heaviest load, adding, of course, the grate-surface for the extra or reserve boiler, this should be entered in the specifications for bidders for boilers, and no bid should be considered which did not give the full extent called for. Many expensive mistakes have been made by purchasers of boilers who have accepted the guarantees of economy and capacity offered by builders, without reference to the extent of grate-surface. After erection the boilers may be proved to have fulfilled the guarantees, on an expert test, with good coal, but afterwards they fail to develop the additional capacity required of them in emergencies, or even their rated capacity when the coal is poorer than that used in the test. The remedy then usually is the costly one of obtaining additional boilers, and sometimes of building a new boiler-house. The purchaser is fortunate if he can, by a change in the style of furnace or of grates, or by building a taller chimney or by introducing forced draft, so increase the capacity of the boilers as to avoid the necessity of buying additional ones.

The extent of heating surface found by the calculation should also be entered in the specifications as the minimum to be bidden upon. Some bidders may not be able to furnish together with the specified extent of grate-surface as small an extent of heating surface as that called for, since their designs are not adapted for such small ratios of heating to grate-surface as those given above, but there is no objection to their furnishing as much more as they choose, and among bidders offering the same grate-surface those offering the greater extent of heating surface should have the preference, other conditions being equal. Capacity for emergencies being obtained by extent of grate-surface, economy of coal will be obtained by extent of heating surface above that needed to give an evaporation at the rate of 6 lbs. per sq. ft. of heating surface per hour.

Bidders' Guarantees.—Guarantees of economy and capacity may be inserted in specifications, but they should be considered secondary as compared with dimensions of grate and heating surface, and no attention should be paid to guarantees of unusual economy offered by any bidder who does not give any more heating surface than other bidders, unless that guarantee is based upon the offer of a special furnace or stoker, which may reasonably be expected to give better economy than a plain furnace when soft coal is used.

Type of Boiler.—The calculations made as above described are applicable to any type of boiler. The selection of a type depends on other considerations than capacity or economy, for these depend upon proportions and not on type. These considerations are safety, durability, convenience, or facility for cleaning and making repairs, ground space occupied, ability to furnish dry steam when overdriven, and last of all, cost.

Materials Used in Boilers.—For the shells, tubes, rivets and braces the material now in almost universal use is a special kind of soft open-hearth steel, low in sulphur and phosphorus and of a tensile strength not exceeding 65,000 lbs. per sq. in. for shell plates and not exceeding 55,000 lbs. per sq. in. for rivets. Prior to the year 1890 steel of higher tensile strength had frequently been used, but it often proved too brittle to withstand the severe strains of service due not only to internal pressure but also to alternate heating and cooling. Before the general introduction of steel for boiler plates (1875 to 1885), a special grade of wrought iron known as "C.H. No. 1" (charcoal hammered) was the favorite material. Wrought iron is still used to some extent for tubes, rivets and braces, but its use is relatively decreasing.

Cast iron is used for fire-doors, grate-bars, manhole and hand-hole plates, headers of water-tube boilers (for pressures under 160 lb.), mud drums (not exceeding 18 in. diameter), and nozzles for

pipe attachments, but there is a tendency to substitute rolled or forged steel for all these purposes except grate bars.

Quality of Steel. (Massachusetts Boiler Rules, 1910.) *Open-hearth Process.*—All plates and rivets used in the construction of steel shells or drums of boilers shall be as specified by the American Society for Testing Materials, 1901.

	Flange or Boiler Steel.	Fire-box Steel.	Extra Soft Steel.
Phosphorus, not to exceed, acid	0.06%	0.04%	0.04%
Phosphorus, not to exceed, basic	0.04%	0.03%	0.04%
Sulphur, not to exceed........	0.05%	0.04%	0.04
Manganese.................	0.30 to 0.60	0.30 to 0.50	0.30 to 0.50
Tensile strength, lbs. per sq.in.	55,000 to 65,000	52,000 to 62,000	45,000 to 55,000
Yield point, not less than.....	½ T. S.	½ T. S.	½ T. S.
Elongation in 8 in. not less than	25%	26%	28%

Steel for rivets shall be of the extra soft class.

For each increase of $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in. a deduction of 1%, and for each decrease of $\frac{1}{16}$ in. in thickness below $\frac{5}{16}$ in. a deduction of $2\frac{1}{2}$ per cent shall be made from the specified elongation.

The report of the A. S. M. E. Boiler Code Committee, 1914, approved by the American Boiler Manufacturers' Association, contains the following:

The steel shall conform to the following requirements:

	FLANGE	FIREBOX
Carbon	Plate ¾ in. thick and under..0.12—0.25% Plates over ¾ in. thick.......0.12—0.30%	
Manganese	0.30—0.60%	0.30—0.50%
Phosphorus, Acid	Not over 0.05%	Not over 0.04%
Phosphorus, Basic	Not over 0.04%	Not over 0.035%
Sulphur	Not over 0.05%	Not over 0.04%
Copper		Not over 0.05%
Tensile strength, lb. per sq. in.	55,000—65,000	55,000—63,000
Yield point, min., lb. per sq. in.	0.5 tens str.	0.5 tens str.
Elongation in 8-in., min., per cent	$\frac{1,500,000}{\text{Tens. str.}}$	$\frac{1,500,000}{\text{Tens. str.}}$

For material over ¾ in. in thickness a deduction of 0.5 from the percentage of elongation shall be made for each increase of ⅛ in. in thickness above ¾ in., to a minimum of 20 per cent.

Fig. 145 shows the correct form for test specimens. The old form, Fig. 146, which makes the tensile strength from 10% to 25% too

high, used by the U. S. Supervising Inspectors for many years, is now abandoned.

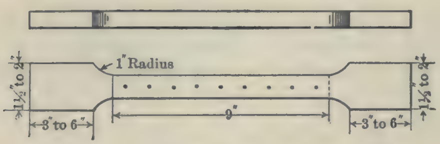

FIG. 145.—SHAPE OF TEST-PIECE.

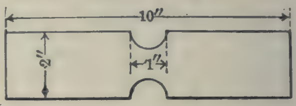

FIG. 146.—INCORRECT TEST-PIECE.

Bending tests.—The test specimen shall be $1\frac{1}{2}$ in. wide, if possible, and of the same thickness as the plate from which it is cut, but for material more than $\frac{3}{4}$ in. thick the specimen may be $\frac{1}{2}$ in. thick. Both before and after quenching the specimen shall bend cold 180° flat on itself without fracture on the outside of the bent portion. The cold bending test shall be made on the material in the condition in which it is to be used, and prior to the quenched bending test it shall be heated to a light cherry red, as seen in the dark, and quenched in water of a temperature between 80° and 90° F. For fire-box steel the homogeneity test of the Penn. R. R. specifications is made (see M. E. Pocket-book, 8th ed. p. 484).

Plates are to be stamped with the heat number, brand and lowest tensile strength, and name and location of manufacturer, as directed by the rules. Plates will be considered up to gage if measuring not over 0.01 inch less than the ordered gage.

Cast steel used in any part of boilers or superheaters shall have not less than 50,000 lbs., and cast iron used in boilers not less than 18,000 lbs. per square inch tensile strength.

Cross pipes connecting steam and water drums and mud drums of water-tube boilers shall be of wrought or cast steel when the working pressure exceeds 160 lbs. per sq. in.

Pressure parts of superheaters, attached to boilers or separately fired, shall be of wrought or cast steel when the working pressure exceed 50 lbs. per sq. in.

Boiler and superheater mountings, such as nozzles, cross pipes, steam pipes, fittings, valves and their bonnets shall be of wrought or cast steel when exposed to steam which is superheated over 80° F. Water-leg and door-frame rings of vertical fire-tube boilers 36 in. or over in diameter, or of locomotive boilers, shall be of wrought or cast steel, or wrought iron.

E. D. Meier, president of the Heine Safety Boiler Co., commenting on these specifications in 1912,* says:

Such steel can safely be depended on with a factor of safety of five, (some laws allow four).

Sulphur makes iron and steel "red short," i. e., brittle at red

* Stevens Institute Indicator, Oct., 1912.

heat. Phosphorus makes them "cold short," i. e., brittle at low temperatures. Both in excess would endanger the work while flanging, bending, or modeling when hot, and again after cooling down. In 1897 it gave me great pleasure to be able to report to the convention of the American Boiler Manufacturers' Association that in more than 250 tests of steel from eight different mills the upper limit in sulphur and in phosphorus had not once been reached.

Large furnaces for heating an entire flange length instead of short sections, and for annealing after all work tending to distort or set up shrinkage strains has been done, insure that the actual structure will carry out the promise of the test piece.

Rivets and stays are now made from steel of the same high quality as boiler plate. There was much prejudice against steel rivets for some years, and high-grade charcoal-iron rivets were prescribed by leading authorities, even after steel plates came into general use. The prejudice was finally overcome by the rational work of the rivet-makers in demonstrating proper methods of heating and driving, differing much from those in vogue with iron rivets.

Tubes also have undergone progressive evolution. About three years ago the largest tube mill in the country publicly announced that it would no longer make the so-called "charcoal" iron tubes. During the last five years the open-hearth steel, hot-rolled, seamless tubes have become the standard for high grade work. Only architects now specify charcoal-iron tubes. Their reverence for the antique is touching and laudable, but should not be extended to metallurgy, which is an essentially modern science.

Some years ago I made exhaustive tests on various makes of steel and iron tubes. The iron ran about 48,000 pounds per square inch tensile strength longitudinally, but only 36,000 transversely, and the steel 59,000 to 60,000 transversely and slightly above 60,000 longitudinally; so that a steel water-tube is about 66 per cent stronger than an iron one. Cold-drawn steel tubes are made by drawing hot-rolled tubes through dies, just as wire is drawn. This process gives the surfaces a polish at the expense of ductility, and tubes thus made cannot be recommended where safety and durability are prime essentials.

Cast iron, used before 1890 very generally for reinforcing manholes, for feed and blow-off pads and for steam saddles, was emphatically condemned in the American Boiler Manufacturers' Association specifications of 1889, and forged steel of best quality is now used for such parts. Cast iron for parts under tensile stress was prohibited, and in 1895 the greatest boiler company of the country marked 125 pounds as the upper limit for cast iron headers.

For some years an uncanny metal called "flowed steel," unknown to metallurgical experts, was recommended to a credulous and undiscriminating public, but it has faded away into the "Niffelheim" from which it came.

Quality of Steel in a Boiler after Thirty Years of Service.—Three horizontal tubular boilers that had been in operation 30 years at the Lake Superior Iron Mines, Ishpeming, Mich., were condemned by an insurance company on account of their age, although they showed no sign of deterioration. The boilers were tested to destruction by hydraulic pressure. In each case no rupture occurred until a pressure of 275 lbs. per sq. in., or upward, was reached, and in each instance the manhole frame proved to be the weakest part of the boiler. Very slight leaks, or "weeping" began at 160 to 180 lbs. Test pieces from one boiler cut from the shell immediately over the fire showed an average tensile strength of 60,460 lbs., elongation in 8 in. 22.5%; reduction of area 53.7%. Analysis gave carbon, 0.13; sulphur, 0.026; phosphorus, 0.097; manganese, 0.27. Test pieces from a sheet at the top of the boiler where it was not subjected to the action of the fire gave an average tensile strength of 70,145 lbs.; elongation 20.1%; reduction of area 47.0%; elastic limit 39,060 lbs. The steel was "Bay State," made about 1877. It was evident that there had been no deterioration of the steel.—(*Power*, Feb. 27, 1912).

It is interesting to note that at the present day steel that gave the results above stated would not be accepted as first quality boiler plate. The first would be rejected for being too high in phosphorus, and the second for too high tensile strength. In the early days of the manufacture of steel for boiler plate high tensile strength and moderately high phosphorus were not considered as objectionable as they now are, but in these early days there were many failures of steel plates by cracking in service, which were generally traced to high tensile strength and brittleness due to high phosphorus.

Boiler Tubes.—Tubes are now generally made of soft steel, but charcoal iron tubes are preferred by some authorities. The American Railway Master Mechanics Association in its revised specifications of 1904 states that locomotive tubes shall be of knobbled, hammered charcoal iron, smooth in surface, and free from laminations, cracks, blisters, pits and imperfect welds. Strips planed from the tubes heated to cherry red and quenched in water shall be bent and hammered down flat at each end without showing crack or flaw, and when nicked and broken shall show a fracture wholly fibrous. A section of tube 12 inches long shall be expanded by a pin tapered $1\frac{1}{2}$ in. per foot till the end is expanded to $1\frac{1}{8}$ times its original diameter without splitting or cracking. A section $2\frac{1}{2}$ in. long placed vertically on the anvil. of a steam hammer and subjected by light blows must crush to a height of $1\frac{1}{8}$ in. without split or crack. Each tube must be tested to 500 lbs. per sq. in. hydraulic pressure.

Etching Test.—In case of doubt as to the quality of material,

the following test shall be made to detect the presence of steel: A section of tube, turned or ground to a perfectly true surface on the end, will be polished free from dirt or cracks, and the end of the tube will be suspended in a bath of nine parts water, three parts sulphuric acid and one part hydrochloric acid. The bath will be prepared by placing water in a porcelain dish, adding the sulphuric and then the hydrochloric acid. The chemical action must be allowed to continue until the soft parts are sufficiently dissolved so that the iron tube will show a decided ridged surface, with the weld very distinct, while the steel tube will show a homogeneous surface.

Upsetting Tubes.—For marine boilers it is often customary to upset or thicken the tubes at the ends for a length of about 2½ in. Greater durability is claimed for such upset tubes. The Parkersburg Iron Co., Parkersburg, W. Va., publishes tables giving the amount of upsetting or increase of outside diameter allowed for tubes of different thicknesses, from which the following figures are taken:

Thickness of tube, B.W.G....	10	9	8	7	6	5	4	¼ in.
Thickness of tube, in........	0.134	0.148	0.165	0.182	0.203	0.219	0.238	0.250
Ordinary upset, in..........	.13	.15	.17	.19	.20	.22	.24	.25
Advisable limit, in..........	.20	.20	.25	.28	.30	.33	.36	.38
Possible, but difficult, in.....	.27	.30	.33	.38	.41	.44	.48	.50

Shells; Water and Steam Drums.—The cylindrical structure, including the ends, of a fire-tube boiler, is usually called the shell. The cylinder superposed on the tubes of a water-tube boiler is called a water and steam drum. Shells of marine boilers of the Scotch type have been built of diameters as large as 16 ft. Water and steam drums of water-tube boilers are rarely made of greater diameter than 42 in.

The thickness of shell for a given pressure is found from the common formula for safe strength of thin cylinders,

$$P = \frac{2tTf}{dF}; \quad \text{whence} \quad t = \frac{PdF}{2Tf},$$

in which P = safe working pressure; T = tensile strength of plate, both in lbs. per sq. in., t = thickness of plate in inches; f = ratio of the strength of a riveted joint to that of the solid plate; F = factor of safety allowed; and d = diameter of shell or drum in inches.

The value taken for T is commonly that stamped on the plates by the manufacturer, f is taken from tables of strength of riveted joints or is computed as shown below, and F must be taken at a figure not less than is prescribed by local or State laws, or, in the case of marine boilers, by the rules of the U. S. Board of Supervising Inspectors, and may be more than this figure if a greater margin of safety is desired.

Strength of Circumferential Seam.—Safe working pressure $P = \frac{4tTf}{dF}$; $t = \frac{PdF}{4Tf}$, notation as above. The strength of a shell against rupture on a circumferential line is twice that against rupture on a longitudinal line, therefore single riveting is sufficient on the circumferential seams while double, triple or quadruple riveting is used for the longitudinal seams.

Riveted Joints.—Figs. 147 to 147*d* show the usual forms of riveted joints. In the cuts of the butt and double strap joints the dotted

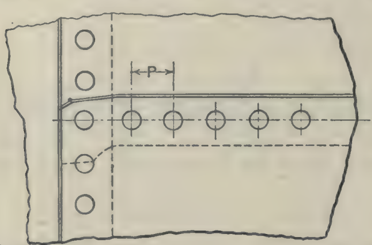

FIG. 147.—LAP JOINT, SINGLE-RIVETED.

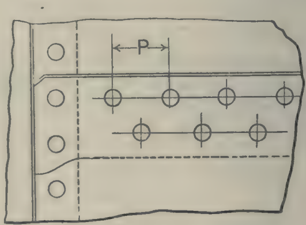

FIG. 147*a*.—LAP JOINT, DOUBLE-RIVETED.

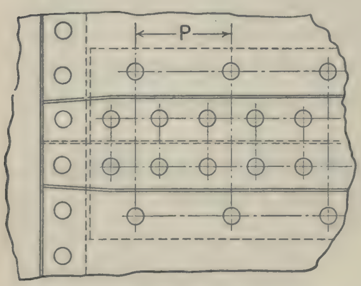

FIG. 147*b*.—BUTT AND DOUBLE STRAP JOINT, DOUBLE-RIVETED.

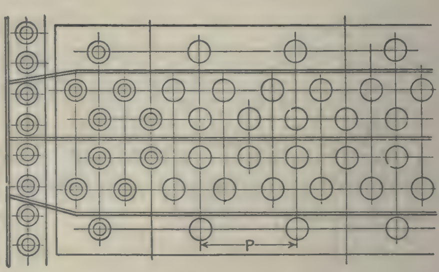

FIG. 147*c*.—BUTT AND DOUBLE STRAP JOINT, TRIPLE-RIVETED.

lines indicate the width of the bottom strap and the solid lines the width of the narrower upper strap. A riveted joint may fail in either one of several ways: 1. By tearing the plate along a line

through a row of rivets. 2. By shearing the rivets. 3. By crushing the rivets or the plate in front of the rivets. 4. If the lap is insufficient, by splitting or shearing the edge of the plate in front of the rivets. 5. By tearing the plate and shearing some of the rivets.

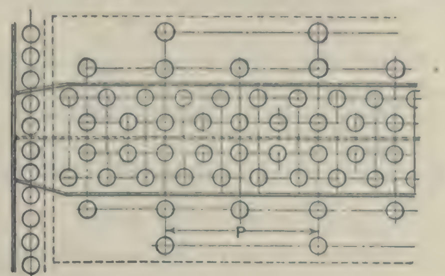

FIG. 147*d*.—BUTT AND DOUBLE STRAP JOINT, QUADRUPLE-RIVETED.

The following rules for proportioning a riveted joint so as to obtain maximum efficiency are given by F. E. Cardullo:

Let t = the thickness of the main plates.
d = the diameter of the rivet-holes.
f = the tensile strength of the plate in pounds per sq. in.
s = the shearing strength of the rivets in pounds per sq. in. when in single shear.
p = the distance between the centers of rivets of the outer row (see Figs. 147*a* and 147*b*) = the pitch in single and double lap riveting = twice the pitch of the inner rows in triple butt strap riveting, in which alternate rivets in the outer row are omitted = four times the pitch in quadruple butt strap riveting, in which the outer row has one-fourth of the number of rivets of the two inner rows.
c = the crushing strength of the rivets or plates in pounds per sq. in.
n = the number of rivets in each group in single shear. (A group is the number of rivets on one side of a joint corresponding to the distance p; = 1 rivet in single riveting, 2 in double riveting, 5 in triple butt strap riveting, and 11 in quadruple butt strap riveting.)
m = the number of rivets in each group in double shear.
s'' = the shearing strength of rivets in double shear, in pounds per sq. in., the rivet section being counted once.
T = the strength of the plate at the weakest section. $= ft(p - d)$.
S = the strength of the rivets against shearing,

$$= 0.7854d^2(ns + ms'').$$

C = the strength of the rivets or the plates against crushing, $= dtc(n + m)$.

In order that the joint shall have the greatest strength possible, the tearing, shearing, and crushing strength must all be equal. In order to make it so,

1. Substitute the known numerical values, equate the expressions for shearing and crushing strength, and find the value of d, taking it to the nearest $\frac{1}{16}$ in.

2. Next find the value of S in the second equation, and substitute it for T in the first equation. Substitute numerical values for the other factors in the first equation, and solve for p.

The efficiency of a riveted joint in tearing, shearing and crushing, is equal to the tearing, shearing or crushing strength, divided by the quantity ftp, or the strength of the solid plate.

The efficiency in tearing is also equal to $(p - d) \div p$.

The maximum possible efficiency for a well-designed joint is

$$E = \frac{m + n}{m + n + (f \div c)}.$$

Empirical formula for the diameter of the rivet-hole when the crushing strength is unknown: Assuming that $c = 1.4f$, and $s'' = 1.75s$, we have by equating C and S, and substituting,

$$d = 1.782t \frac{f(n + m)}{s(n + 1.75m)}.$$

Margin. The distance from the center of any rivet-hole to the edge of the plate should be not less than $1\frac{1}{2}d$. The distance between two adjacent rivet centers should not be less than $2d$. It is better to increase each of these dimensions by $\frac{1}{8}$ in.

The distance between the rows of rivets should be such that the net section of plate material along any broken diagonal through the rivet-holes should be not less than 30 per cent greater than the plate section along the outer line of rivets.

The thickness of the inner cover strap of a butt joint should be $\frac{3}{4}$ of the thickness of the main plate or more. The thickness of the outer straps should be $\frac{5}{8}$ of the thickness of the main plate or more.

Steam Tightness. It is of great importance in boiler riveting that the joint be steam tight. It is therefore necessary that the pitch of the rivets nearest to the calked edge be limited to a certain function of the thickness of the plate. The Board of Trade rule for steam tightness is

$$p = Ct + 1\tfrac{5}{8} \text{ in.},$$

where p = the maximum allowable pitch in inches;
t = the thickness of main plate in inches;
C = a constant from the following table.

No. of rivets per group....	1	2	3	4	5
Lap joints...............	$C=1.31$	2.62	3.47	4.14	....
Double-strapped joints....	$C=1.75$	3.50	4.63	5.52	6.00

The pitch should not exceed ten inches under any circumstances.

When the joint has been designed for strength, it should be checked by the above formula. Should the pitch for strength exceed the pitch for steam tightness, take the latter, substitute it in the formula

$$ft(p - d) = 0.7854d^2(ns + ms''),$$

and solve for d. If the value of d so obtained is not the diameter of some standard size rivet, take the next larger $\frac{1}{16}$ in.

Efficiency of Riveted Joints. (Mass. Boiler Rules, 1910.)*

X = efficiency = ratio of strength of unit length of riveted joint to the strength of the same length of a solid plate.

T = tensile strength of the material, in pounds per square inch.

t = thickness of plate, in inches.

b = thickness of butt strap, in inches.

P = pitch of rivets, in inches, on the row having the greatest pitch.

d = diameter of rivet, after driving, in inches.

a = cross-section of rivet after driving, in square inches.

s = strength of rivet in single shear, in pounds per square inch.

S = strength of rivet in double shear, in pounds per square inch.

c = crushing strength of rivet, in pounds per square inch.

n = number of rivets in single shear in a length of joint equal to P.

N = number of rivets in double shear in the same length of joint.

For single-riveted lap joints:

A = strength of solid plate = PtT.

B = strength of plate between rivet holes = $(P-d)tT$.

C = shearing strength of one rivet = nsa.

D = crushing strength of plate in front of one rivet = dtc.

$X = \frac{B}{A}$ or $\frac{C}{A}$ or $\frac{D}{A}$, whichever is least.

For double-riveted lap joints:

A and B as above, C and D to be taken for two rivets.

$X = B$, C, or D (whichever is least) divided by A.

For butt and double strap joint, double-riveted:

A = strength of solid plate = PtT.

B = strength of plate between rivet holes in the outer row = $(P-d)tT$.

C = shearing strength of two rivets in double shear, plus shearing strength of one rivet in single shear = $NSa + nsa$.

D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row = $(P-2d)tT + nsa$.

E = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row = $(P-2d)tT + dbc$.

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* The same rules are given in the A. S. M. E. Boiler Code of 1914, which was modeled on the Massachusetts Rules. It is published in pamphlet form by the American Society of Mechanical Engineers.

F = crushing strength of plate in front of two rivets, plus the crushing strength of butt strap in front of one rivet $= Ndtc + ndbc$.

G = crushing strength of plate in front of two rivets, plus the shearing strength of one rivet in single shear $= Ndtc + nsa$.

$X = B, C, D, E, F$, or G (whichever is least) divided by A.

For butt and double strap joint, triple-riveted:

The same as for double-riveted, except that four rivets instead of two are taken for N in computing C, F, and G.

For butt and double strap joint, quadruple-riveted:

A, B, and D the same as for double-riveted joints.

C = shearing strength of eight rivets in double shear and three rivets in single shear $= NSa + nsa$.

E = strength of plate between rivet holes in the third row (the outer row being the first) plus the shearing strength in single shear of two rivets in the second row and one rivet in the outer row $= (P-4d)tT + nsa$.

F = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row $= (P-2d)tT + dbc$.

G = strength of plate between rivet holes in the third row, plus the crushing strength of butt strap in front of two rivets in the second row and one rivet in the outer row $= (P-4d)tT + ndbc$.

H = crushing strength of plate in front of eight rivets, plus the crushing strength of butt strap in front of three rivets $= Ndtc + ndbc$.

I = crushing strength of plate in front of eight rivets, plus the shearing strength in single shear of two rivets in the second row and one in the outer row $= Ndtc + nsa$.

$X = B, C, D, E, F, G, H$, or I (whichever is least) divided by A.

The Massachusetts Rules allow the crushing strength of mild steel to be taken at 95,000 lbs. per sq. in. The maximum shearing strength of rivets, in lbs. per sq. in. of cross-section, is taken as follows:

In single shear, iron, 38,000; steel, 42,000.

In double shear, iron, 70,000; steel, 78,000.

The A. S. M. E. Boiler Code also allows 95,000 lbs. per sq. in. for crushing strength, but for shearing strength of rivets allows:

In single shear, iron, 38,000 steel, 44,000.

In double shear, iron, 76,000; steel, 88,000.

Convex or Bumped Heads.—When the head is of material of the same quality and thickness as that of the shell, the head is of equal strength with the shell when the radius of curvature of the head equals the diameter of the shell, or when the rise of the curve=0.134 diam. of shell. Fig. 148.

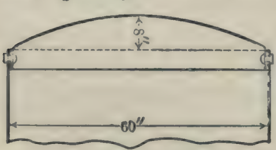

FIG. 148.—BUMPED HEAD.

Thickness of Plates; Riveting. (Mass. Boiler Rules, 1910.)—The longitudinal joints of a boiler, the shell or drum of which exceeds 36 in. diameter, shall be of butt and double strap construction; if it does not exceed 36 in. lap-riveted construction

may be used, the maximum pressure on such shells being 100 lbs. per sq. in.

The longitudinal joints of horizontal return-tubular boilers shall be located above the fire-line of the setting. A horizontal return-tubular, a vertical tubular, or a locomotive type boiler shall not have a continuous longitudinal joint over 12 ft. in length.*

The thickness of plates in a shell or drum shall be of the same gage. The minimum thickness of plates used in the construction of a boiler shall be $\frac{1}{4}$ in. The minimum thickness of shell plates shall be as follows:

Diam. 36 in. or under, $\frac{1}{4}$ in.; over 36 to 54 in., $\frac{5}{16}$ in.; over 54 to 72 in., $\frac{3}{8}$ in.; over 72 in., $\frac{1}{2}$ in.

Minimum thickness of butt straps:

Thickness of plates, in. . .	$\frac{1}{4}$ to $\frac{11}{32}$	$\frac{3}{8}$ to $\frac{13}{32}$	$\frac{7}{16}$ to $\frac{15}{32}$	$\frac{1}{2}$ to $\frac{9}{16}$	$\frac{5}{8}$ to $\frac{3}{4}$	$\frac{7}{8}$	1 to $1\frac{1}{8}$	$1\frac{1}{4}$
Min. thickn. of straps. in.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$

Minimum thickness of tube sheets:

Diam. of tube sheet. in	42 or under	over 42 to 54	over 54 to 72	over 72
Thickness of tube sheet, in.	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$

Minimum thickness of convex heads, $t = \frac{d}{4}\frac{FP}{T}$; d = diameter in inches; $F = 5$ = factor of safety; P = working pressure, lbs. per sq. in.; T = tensile strength stamped on the head.

$$\left[\text{For } T = 50{,}000,\ t = \frac{dP}{40{,}000};\ \text{for } T = 60{,}000,\ t = \frac{dP}{48{,}000}\right].$$

When a convex head has a manhole opening the thickness is to be increased not less than $\frac{1}{8}$ in.

[The A. S. M. E. Boiler Code specifies a higher factor of safety, 5.5, and adds $\frac{1}{8}$ in. to the thickness, making the formula $\frac{t = 5.5PR}{2\,T}$ $+ \frac{1}{8}$ in., R being the radius to which the head is dished, in inches. When R is less than $0.8d$ the thickness shall be at least that found by the formula when $R = 0.8d$. Dished heads with the pressure on the convex side are allowed a maximum working pressure equal to 60% of that for heads of the same dimensions with the pressure on the concave side. When the dished head has a manhole opening the thickness as found by these rules shall be increased by not less than $\frac{1}{8}$ in. The corner radius of a dished head shall be not less than $1\frac{1}{2}$ in. nor more than 4 in., and not less than 3% of R. A manhole open-

* There seems to be no good reason for this restriction. It is not found in the A.S.M.E. Code.

ing in a dished head shall be flanged to a depth not less than three times the thickness of the head measured from the outside.]

Minimum thickness of plates in flat-stayed surfaces, $\frac{5}{16}$ in.

The ends of staybolts shall be riveted over or upset.

Rivets shall be of sufficient length to completely fill the rivet holes and form a head equal in strength to the body of the rivet.

Rivets shall be machine driven wherever possible, with sufficient pressure to fill the rivet holes, and shall be allowed to cool and shrink under pressure.

Rivet holes shall be drilled full size with plates, butt straps and heads bolted in position; or they may be punched not to exceed ¼ in.

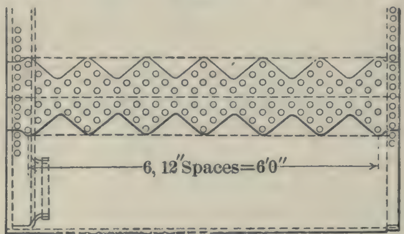

FIG. 149.—QUADRUPLE-RIVETED JOINT.

FIG. 150.—SECTION OF SEAM ON UNDER HALF OF BOILER.

less than full size for plates over $\frac{5}{16}$ in. thick, and ⅛ in. or less for plates not exceeding $\frac{5}{16}$ in. thick, and then drilled or reamed to full size with plates, butt straps and heads bolted up in position.

Quadruple Riveted Joint.—F. W. Dean, (*Power,* May 16, 1911) condemns the use of that form of butt and strap joint in which the outside strap is narrower than the inside. A part of the joint is lapped and in that part the rivets are overhung and in single shear, and the whole joint may be deformed under strain. Fig. 149 shows the method of riveting designed by Mr. Dean (after German marine practice) for a horizontal tubular boiler 84 in. diameter, 192 3 in. tubes 20 ft. long, 3056 sq. ft. of heating surface. Both butt straps are the same size, ⅝ in. thick. The rivets are ⅞ in. diam., 4 in. pitch. An efficiency of 92 per cent may be obtained with this form of joint. The plates at the circumferential seams are thinned down on the under half of the boiler, as shown in Fig. 150 to avoid having too great a double thickness of seam.

Working Pressure on Boilers with Triple Riveted Joints.—A triple riveted double butt and strap joint, carefully designed, may be made to have an efficiency something higher than 85 per cent. Good boiler plate steel may be considered to have a tensile strength of 55,000 lbs. per sq. in. Taking these figures and a factor of safety of 5, we have safe working pressure

$$P = \frac{2Ttf}{dF} = \frac{2 \times 55{,}000 \times t \times 0.85}{5d} = \frac{18700t}{d},$$

from which the following table is calculated.

SAFE WORKING PRESSURE FOR SHELLS WITH JOINTS OF 85% EFFICIENCY.

Thickness, inches	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
Diameter, inches 24	195	247											
30	156	195	234										
36	130	162	195	227	260								
42	111	139	167	195	223	250							
48	...	122	146	170	195	219	243						
54	...	108	130	151	173	195	216	238					
60	...	...	117	136	156	175	195	214	233				
66	...	...	106	124	142	159	177	195	212	230			
72	...	...	...	114	130	146	162	179	195	211	227		
78	...	...	...	...	120	135	150	165	180	195	210	225	
84	...	...	...	...	...	125	139	153	167	181	195	209	223
90	...	...	...	...	...	117	130	143	156	169	182	195	208
96	...	...	...	...	...	...	121	134	146	158	170	183	195

Shells of externally-fired boilers are rarely made over $\frac{9}{16}$ in. thick.

Pressures Allowed on Boilers. (Mass. Boiler Rules, 1910.)—The pressure allowed on a boiler constructed wholly of cast iron shall not exceed 25 lbs. per sq. in.

The pressure allowed on a boiler the tubes of which are secured to cast-iron headers shall not exceed 160 lbs. per sq. in.

The maximum pressure to be allowed on a shell or drum of a boiler shall be determined from the minimum thickness of the shell plates, the lowest tensile strength stamped on the plates by the manufacturer, the efficiency of the longitudinal joint or of the ligament between the tube holes, whichever is least, the inside diameter of the outside course, and a factor of safety not less than five.

The lowest factor of safety to be used for boilers the shells or drums of which are exposed to the products of combustion, and the longitudinal joints of which are lap riveted, shall be as follows: 5 for boilers not over 10 years old; 5.5 for boilers over 10 and not over 15 years old; 5.75 for boilers over 15 and not over 20 years old; 6 for boilers over 20 years old. The lowest factor of safety to be used for boilers the longitudinal joints of which are of butt and double strap construction is 4.5.

A hydrostatic test is to be applied if in the judgment of the inspector or of the insurance company it is advisable. The maximum pressure in a hydrostatic test shall not exceed $1\frac{1}{2}$ times the maximum allowable working pressure, except that twice the maximum allowable working pressure may be applied on boilers permitted to carry not over 25 lbs. pressure, or on pipe boilers.

All steam boilers and their appurtenances except [here follows a list of exceptions, covering locomotives, agricultural boilers, heating boilers, boilers of not more than 3 H.P., and boilers under the jurisdiction of the United States] shall be thoroughly inspected internally and externally at intervals of not over one year, and shall

not be operated at pressures in excess of the safe working pressure stated in the certificate of inspection.

Making a Boiler Shell.—The several sheets of which the shell is to be constructed are sheared to the exact size called for in the drawings, the rivet holes are located by means of wooden templates and their centers prick punched, or else the holes are spaced and punched by automatic machinery. The holes for all nozzles and screwed pipe connections are located and punched or cut. The operation of punching a rivet hole is shown in Fig. 151. The metal in the immediate vicinity of the hole is strained and hardened by the action of the punch, and therefore it is required in the best boiler-making practice that the holes be punched smaller than their full size and finished to size by drilling or reaming after the plates have been rolled and bolted in position.

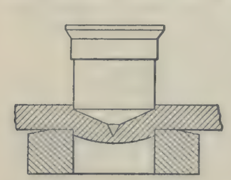

Fig. 151.—Punching a Plate.

After cutting the holes the edges of the plates are planed or cut with chisels to make smooth the edges that are left rough in shearing, and where lap joints are to be made the plates are beveled to a thin edge so that the joint may be made tight by calking. Fig. 152 shows how plates are "scarfed" and joined together at the meeting point of a horizontal and a girth lap joint.

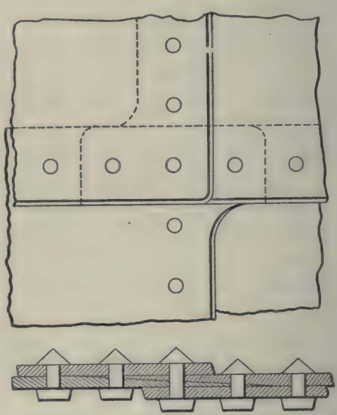

Fig. 152.—Plates Scarfed at Meeting of Joints.

After punching, drilling and planing, the plate is rolled into the required shape, by being passed back and forth between three rolls, the top one of which is forced downward by screws as the radius of the bend becomes smaller. The bending is done slowly so as not to overstrain the metal, the amount of curvature made at each pass being less for a thick plate than for a thin one.

After rolling to shape, the rivet holes of a joint are brought together by means of drift pins and bolts and such irregularities as are found to exist, on account of the change in dimensions with rolling, are reamed out by passing a reamer or drill, the full size of

the rivet hole, through each pair of holes which come together. After a few rivet holes have been drilled, stay rivets are put in and headed over and the drift pins or bolts may be taken out as the stay rivets hold the joints in position, and the riveting of the joint is then completed. Hydraulic or other machine riveting is used wherever possible, as it generally makes a tighter joint than hand riveting.

Flanged heads are usually formed to shape in hydraulic presses, the metal being heated to redness. It is important to heat the plate evenly throughout and to complete the flanging while the metal is still at a red heat. Flanging at a "blue" heat, that is, below redness, is apt to cause cracking. After flanging the head should be annealed by heating to dull red in an annealing furnace and cooling slowly.

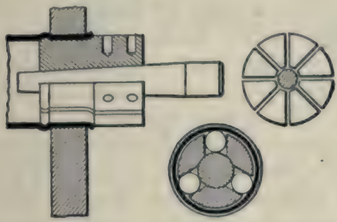

FIG. 153.—TAPER-PIN TUBE EXPANDER.

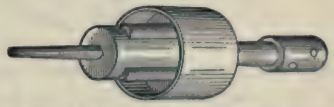

FIG. 154.—ROLLER EXPANDER.

Holes for tubes are cut in the tube sheets by a spiral punch or a revolving cutter. The tubes are secured to the tube sheets by means of expanding tools, such as are shown in Figs. 153 and 154. Care must be taken to continue the expanding process until a thoroughly tight joint is made, pressing the tube against the tube sheet sufficiently to cause a slight groove in the tube, but not so far as to needlessly thin down the tube. When the expanding is properly done the tube sheets are strongly stayed by the tubes so that no flaring or beading over of the end of the tube is necessary, but it is customary in fire-tube boilers to form a bead on the end of the tube and make a good finish. Figs. 155 and 156 show two examples of expanded tubes, the first in which the tube is merely expanded; the second one shows the tube flared at the end after expanding.

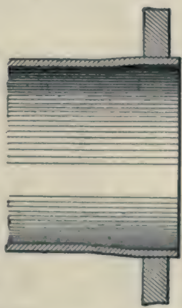

FIG. 155. — TUBE EXPANDED INTO SHEET.

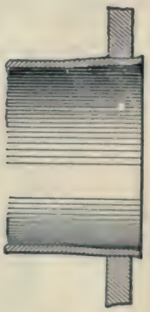

FIG. 156.—EXPANDED AND FLARED.

Mass. Boiler Rules.—Tube holes shall be drilled full size, or they may be punched not to exceed $\frac{1}{2}$ in. less than the full size, and then drilled, reamed or finished full size with a rotating cutter. The edge of tube holes shall be chamfered to a radius of about $\frac{1}{16}$ in. A fire-tube boiler shall have the ends of the tubes substantially beaded. The ends of all tubes, suspension tubes and nipples shall be flared not less than $\frac{1}{8}$ in. over the diameter of the tube hole on all water-tube boilers and superheaters, and shall project through the tube sheets or headers not less than $\frac{1}{4}$ in. nor more than $\frac{1}{2}$ in. Separately fired superheaters shall have the tube ends protected by refractory material where they connect with drums or headers.

Holding Power of Expanded Tubes. (*The Locomotive,* Sept. 1893.)—Tubes 3 in. external diameter, 0.109 in. thick were expanded in a $\frac{3}{8}$-in. plate by rolling with a Dudgeon expander, without the projecting part being flared or beaded. Stress was applied to draw the tubes out of the plates. The observed stress which caused yielding was, in three specimens, 6500, 5000 and 7500 lbs. Two other specimens were flared so that the diameter of the extreme end of the tube, projecting $\frac{3}{16}$ in. beyond the plate was 3.2 in., the diameter of the tube where it entered the plate being 3.1 in. The observed stress which caused the yielding of these specimens was 21,000 and 19,500 lbs. *The Locomotive* estimates that the factor of safety of the plain rolled tubes is nearly 4 and that of the flared tubes about 15 against the stress to which they are subjected in a boiler at 100 lbs. gage pressure. It is considered that the tubes act as stays for that portion of the flat head that is within two inches of the upper row of tubes, and that the segment above this (except that portion that lies with 3 ins. of the shell) requires to be braced.

The stress that acts on each tube tending to pull it out of the head may be calculated as follows: Multiply the area of that portion of the head that is stayed by the tubes, in square inches, minus the sum of the areas corresponding to the external diameter of the tubes, by the maximum pressure of steam the boiler is allowed to carry in lbs. per sq. in., and divide the product by the number of tubes.

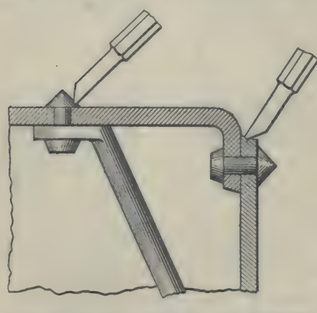

FIG. 157.—CALKING OF JOINTS AND RIVETS.

Calking.—Fig. 157 shows the operation of calking the edge of a lap seam and also calking the head of a rivet. A round-nosed tool should be used in order to avoid cutting the plate. The tool is struck with a hammer with sufficient force to drive the edge of the plate or of the rivet

head down to a firm bearing so as to close the joint completely and prevent leaks. Too heavy a blow is apt to open the joint.

Braces and Stays.—The flat surfaces of a boiler which are not stayed by the tubes require to be stayed by other means. "Through"

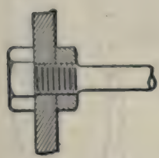

FIG. 158.—END OF A THROUGH STAY.

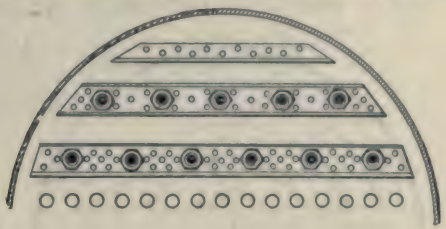

FIG. 159.—CHANNEL REINFORCEMENT FOR STAYS.

stays, which run direct from one head to the other are commonly used in marine boilers of the Scotch type, see Fig. 100, page 350, and to some extent in large high-pressure return boilers. Fig. 158 shows

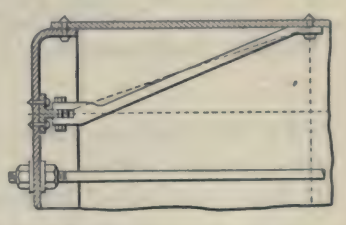

FIG. 160.—DIAGONAL AND THROUGH BRACING.

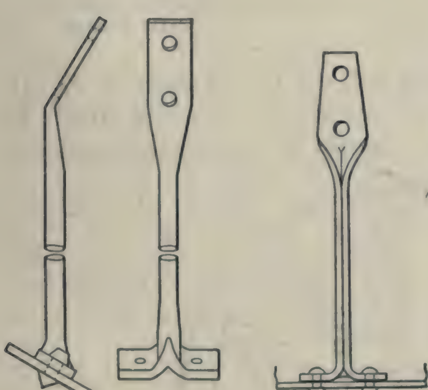

FIG. 161.—CROW-FOOT BRACES.

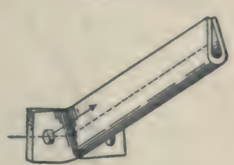

FIG. 162.—BRACE MADE OF BENT PLATE.

one method of securing the end of a through stay rod to the head. Fig. 159 shows channel bars riveted to the inside of a boiler head to reinforce the sheet at the through stay connections.

Fig. 160 shows one form of diagonal stay and also a through stay.

Fig. 161 shows an old form of "crow-foot" brace, used for bracing tubular boilers, and Fig. 163 shows the position of the feet of these

braces in the head, the little circles representing the position of the rivet holes. The dotted lines enclose the area that requires bracing.

Fig. 162 shows a common form of crow-foot brace made out of steel plate bent to shape. It is known as the McGregor brace.

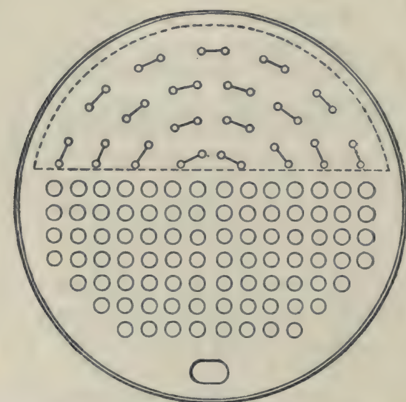

FIG. 163.—ARRANGEMENT OF STAYS AND TUBES.

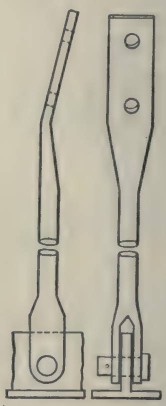

FIG. 164.—BRACES WITH T-BARS.

Fig. 164 shows the braces used with the T-irons shown in Fig. 165. The T-bars are riveted to the head for attachment of the stays. Fig. 166 shows methods of fastening stays to the heads and to the shell.

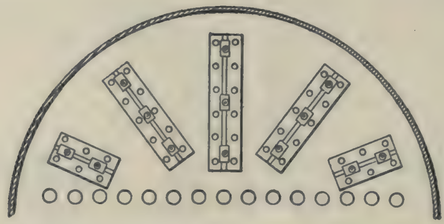

FIG. 165.—T-BAR ATTACHMENT FOR STAYS.

Fig. 167 shows three methods of bracing the flat top or "crown sheet" of a fire box or combustion chamber, such as that of a locomotive, or of an internally fired marine boiler. At the left a pair of "crown bars" is shown in section. The bars extend the width of the fire box and are bent down and forged into feet at the end so as to rest on the edges of the side plates. The downward pressure of steam, which tends to crush in the flat top, is conveyed by bolts and nuts

to caps which straddle a pair of bars. In the two other methods, shown at the right, the load is transmitted by stays to the upper shell of the boiler.

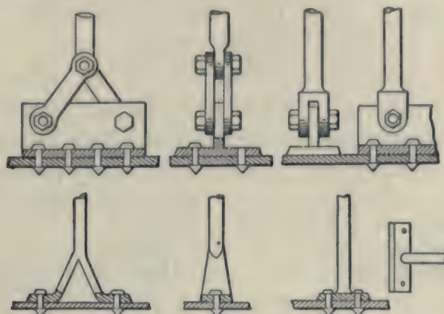

FIG. 166.—METHODS OF FASTENING BRACES.

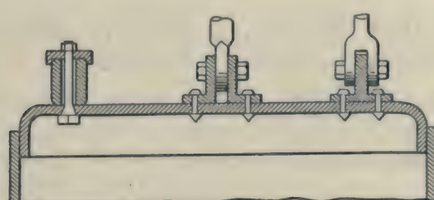

FIG. 167.—METHODS OF BRACING A CROWN SHEET.

Allowable Stresses on Braces and Staybolts. (Massachusetts Rules.)—The maximum allowable stress per square inch net cross-sectional area of stays and stay bolts shall be as follows: Weldless mild steel, head to head or through stays, 8000 lbs., 9000 lbs.; diagonal or crow-foot stays, 7500 lbs., 8000 lbs.; mild steel or wrought-iron staybolts 6500 lbs., 7000 lbs. The first figure in each case is for size up to $1\frac{1}{4}$ in. diameter or equivalent area, the second for size over $1\frac{1}{4}$ in. or equivalent area.

The A. S. M. E. Boiler Code allows for welded stays 6000 lbs. per sq. in.; for unwelded stays, (a) 7500; (b) 9500; (c) 8500. (a) less than 20 diameters long, screwed through plates with ends riveted over; (b) lengths between supports not exceeding 120 diameters; (c) exceeding 120 diameters.

Stay-bolts.—Stay-bolts in water-legs are subject not only to longitudinal stress due to the boiler pressure, and to corrosion, but also to bending stress caused by relative motions of the outer and inner sheets of the furnace or water-leg due to the variations in temperature to which the two are subjected. A stay-bolt usually

fails by transverse fracture close to the outer sheet, which is supposed to be due to the fact that the fire-box sheet is generally thinner than the outer sheet, and therefore holds the end of the stay less rigidly. Fig. 168 shows a stay-bolt drilled with a small hole at one end through which water will be blown out as soon as a fracture extends far enough across the section to reach the hole, thus calling attention to the failure of the stay. Fig. 169 shows a better form, in which the hole extends the whole length of the stay. The inner portion of the stay is turned to ⅛ in.

FIG. 168.—STAY BOLT, DRILLED AT ONE END.

FIG. 169.—HOLLOW STAY BOLT.

smaller diameter than the ends, in order to make the stay more flexible and diminish the chances of fracture.

Flexible Spring Stay-bolt.—H. V. Wille, (*Trans. A. S. M. E.,* 1909) describes a flexible stay-bolt made of oil-tempered spring steel that will safely stand a tensile stress of 100,000 lbs. per sq. in. Its high elastic limit makes it possible to reduce the diameter to ⅜ in. or less. The bolts are slightly enlarged and threaded at the ends and screwed into soft steel end pieces which are screwed into the plates and headed up in the usual manner (Fig. 170).

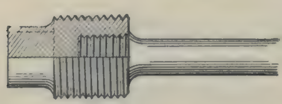

FIG. 170.—FLEXIBLE STAY-BOLT.

Stay-bolts fail not because of the tensional loads upon them, but from flexural stresses induced by the vibration resulting from the greater expansion of the fire-box sheets than of the outside sheets. It is general practice to recess the bolts below the base of the threads and this has effected a slight reduction in the fiber stress, but practically no effort has been made to design a bolt to meet the flexural stresses or even to calculate their magnitude. The stress increases in direct proportion to the diameter and decreases as the square of the distance between the sheets.

Flat Surfaces Supported by Stay-bolts. A. J. Toppin (*Power,* Dec. 24, 1912).—There seems to be a difference of opinion relative to the allowable pressure for a given thickness of plate and pitch of rivets. Formulas by different authorities give notably different results. Massachusetts, Ohio and the city of Detroit employ the formula:

$$P = \frac{66(t+1)^2}{S^2 - 6},$$

in which P = safe working pressure in pounds per square inch; t = thickness of plate in sixteenths of an inch; 66 = a constant determined by experiment; S = maximum pitch in inches.

The United States Government rule is:

$$P = \frac{k \times t^2}{S^2},$$

in which P, t, and S are the same symbols as in the previous formula, and k is a constant depending on the method of staying. For screwed stays riveted over and plates not exceeding $\frac{7}{16}$ in. thick, $k = 112$. For the same conditions and plates over $\frac{7}{16}$ in. thick, $k = 120$.

To determine the area of bolt necessary to sustain the load, let P = pressure in lbs. per sq. in.; $S_{\text{max.}}$ = maximum pitch in inches; $S_{\text{min.}}$ = minimum pitch in inches; A = net area under pressure in square inches; D = outside diameter of stay-bolt in inches; T = the allowable tensile strength of the stay-bolt in lbs. per sq. in.; d = diameter at root of thread of stay-bolt.

The net area supported by one stay-bolt would be the product of the two pitches minus the area of stay-bolt at the root of the thread, or

$$A = (S_{\text{max.}} \times S_{\text{min.}}) - \frac{\pi d^2}{4}.$$

The load sustained by the stay-bolt would be P times this area. The strength of the stay-bolt would be $T \times \frac{\pi d^2}{4}$. As this must balance the load

$$T \times \frac{\pi d^2}{4} = P\left[(S_{\text{max.}} \times S_{\text{min.}}) - \frac{\pi d^2}{4}\right].$$

Transposing,

$$d = 2\sqrt{\frac{PS_{\text{max.}} \times S_{\text{min.}}}{\pi(T + P)}}.$$

Stay-bolts $1\frac{1}{4}$ in. in diameter and under, generally have 12 threads per inch and the outside diameter

$$D = d + 0.1443.$$

Substituting in the foregoing, we obtain

$$D = 2\sqrt{\frac{PS_{\text{max.}} \times S_{\text{min.}}}{\pi(T + P)}} + 0.1443.$$

The value of T varies according to different authorities. Massachusetts allows only 6500 lbs. per square inch on mild steel or wrought-iron stay-bolts up to and including $1\frac{1}{4}$ in. diameter. The United States Government allows 8000 for tested steel stays $1\frac{1}{4}$ to $2\frac{1}{2}$ in. diameter when not forged or welded.

For hollow stays the reduction in area due to the diameter of the hole must be taken into account in computing the strength of the stay.

From these formulae Mr. Toppin calculates a series of tables for the allowable pressures corresponding to different diameters and pitches of stays and thicknesses of plates and plots the curves shown in Figs. 171 and 172.

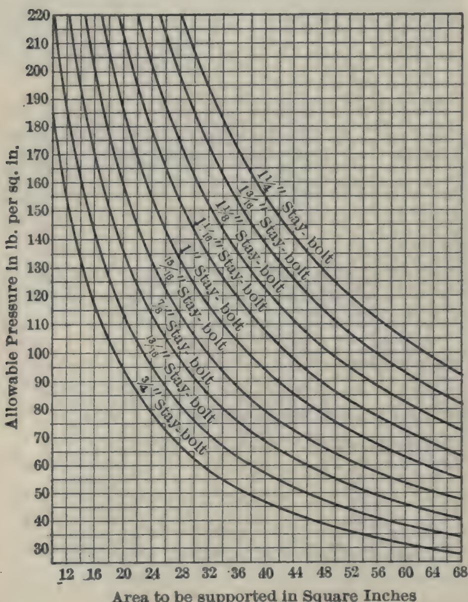

FIG. 171.—ALLOWABLE PRESSURES ON STAY-BOLTS AT 6500 LBS. STRESS.

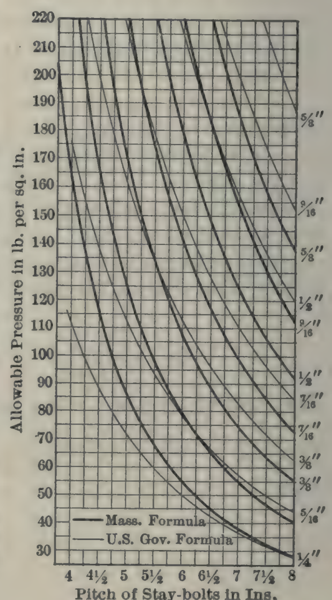

FIG. 172.—ALLOWABLE PRESSURES ON PLATES OF VARIOUS THICKNESS AND PITCHES.

For calculating allowable pressure: at 7000 lbs. per square inch stress, multiply the pressure given in tables by 1.077. At 7500 lbs. multiply by 1.157. At 8000 lbs. multiply by 1.232. At 6000 lbs. multiply by 0.922.

ALLOWABLE PRESSURES ON STAY-BOLTED FLAT SURFACES ACCORDING TO MASSACHUSETTS FORMULA.

Thickness of Plate in Inches.	Allowable Pressures on Stay-bolted Flat Plate. Varying Pitch and Thickness.																			
	Maximum Pitch in Inches.																			
	4	4⅛	4¼	4⅜	4½	4⅝	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾	8
¼	165	149	136	125	115	107	99	86	76	68	61	55	49	45	41	38	35	32	30	28
5/16	237	215	197	180	166	154	143	125	110	98	87	79	71	65	60	55	51	47	43	40
⅜					227	210	195	170	150	133	119	107	97	89	81	75	69	64	59	55
7/16								222	195	174	156	140	127	116	106	98	90	84	78	72
½										220	197	178	161	147	135	124	114	106	98	92
9/16												220	199	182	166	153	141	131	122	113
⅝														220	201	185	171	158	147	137

The above table was calculated according to Massachusetts formula

$$P = \frac{66(t+1)^2}{S^2 - 6},$$

in which P = allowable pressure in pounds per square inch; S = maximum pitch in inches; t = thickness of plates in sixteenths of an inch; 66 = a constant determined by experiment.

ALLOWABLE PRESSURES ON STAY-BOLTED FLAT SURFACES ACCORDING TO U. S. GOVERNMENT FORMULA.

Thickness of Plate in Inches.	Allowable Pressures on Stay-bolted Flat Plates. Varying Pitch and Thickness. Maximum Pitch in Inches.																			
	4	4⅛	4¼	4⅜	4½	4⅝	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾	8
¼	112	105	99	93	88	83	79	71	65	59	54	49	45	42	39	36	34	31	29	28
5/16	175	164	155	146	138	134	124	112	101	92	84	77	71	66	61	57	53	49	46	43
⅜			223	210	199	188	178	161	149	133	122	112	103	95	88	82	76	71	67	64
7/16								215	195	178	163	149	138	127	118	109	102	95	89	83
½												213	196	181	168	156	146	136	128	120
9/16															213	198	184	172	161	151
⅝																		213	199	187

The above table calculated according to the U. S. Government formula,

$$P = \frac{kt^2}{S^2},$$

in which k = a constant; S = max. pitch; t = thickness of plate in sixteenths of an inch; k = 112 for plates up to 7/16 in.; k = 120 for plates over 7/16 in.

The A. S. M. E. Boiler Code gives the same formula as the U. S. Government with the following values of the constants: For stays screwed through plates with ends riveted over, plates not over $\frac{7}{16}$ in. thick, C = 112; over $\frac{7}{16}$ in. thick, C = 120; for stays screwed through plates and fitted with single nuts outside of plate, C = 135; for stays fitted with inside nuts and outside washers, the diameters of washers not less than $0.4S$ and thickness not less than t, C = 175.

Size of Boiler Tubes.—The following table gives the dimensions of the tubes commonly used in steam boilers, together with their calculated surface per foot of length, and the length per square foot of surface, internal and external:

External Diameter. In.	Standard Thickness. In.	Inside Diameter. In.	Inside Surface per Foot of Length.	Length per Sq.ft. of Inside Surface.	Outside Surface per Foot of Length, Sq.ft.	Length per Sq.ft. Outside Surface, Ft.	Internal Area, Sq.ft.	External Area, Sq.ft.
2	.095	1.810	0.4738	2.110	0.5236	1.910	0.0179	0.0218
2¼	.095	2.060	.5393	1.854	.5890	1.698	.0231	.0276
2½	.109	2.282	.5974	1.674	.6545	1.528	.0284	.0341
2¾	.109	2.532	.6629	1.508	.7199	1.389	.0350	.0412
3	.109	2.782	.7283	1.373	.7854	1.273	.0422	.0491
3¼	.120	3.010	.7880	1.269	.8508	1.175	.0494	.0576
3½	.120	3.260	.8535	1.172	.9163	1.091	.0580	.0668
3¾	.120	3.510	.9189	1.088	.9817	1.018	.0672	.0767
4	.134	3.732	.9770	1.024	1.0472	0.955	.0760	.0873

Flues Subjected to External Pressure.—The General Rules and Regulations of the U. S. Board of Supervising Inspectors, Steamboat Inspection Service, 1909, give the following rules for flues subjected to external pressure only:

Plain lap-welded flues 7 to 13 in. diameter.

Furnaces.—The tensile strength of steel used in the construction of corrugated or ribbed furnaces shall not exceed 67,000, and be not less than 54,000 lbs.; and in all other furnaces the minimum tensile strength shall not be less than 58,000, and the maximum not more than 67,000 lbs. The minimum elongation in 8 inches shall be 20%.

All corrugated furnaces having plain parts at the ends not exceeding 9 inches in length (except flues especially provided for),

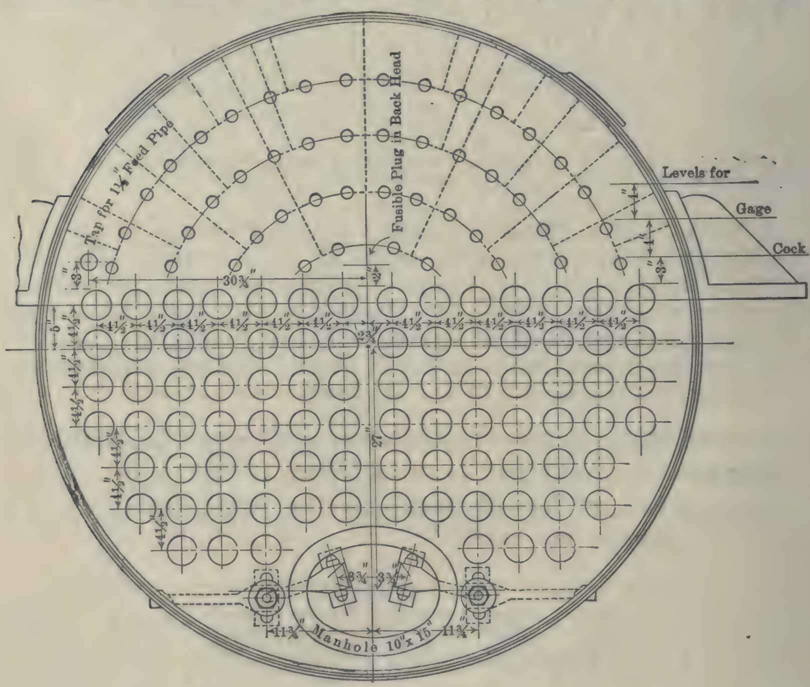

FIG. 173.—TUBE-SPACING IN A HORIZONTAL BOILER.

when new, and made to practically true circles, shall be allowed a steam pressure in accordance with the formula $P = C \times T \div D$.

P = pressure in lbs. per sq. in., T = thickness in inches, C = a constant, as below.

Leeds suspension bulb furnace.....	$C=17,000$, T not less than $\frac{5}{16}$ in.
Morison corrugated type..........	$C=15,600$, T not less than $\frac{5}{16}$ in.
Fox corrugated type..............	$C=14,000$, T not less than $\frac{5}{16}$ in.
Purves type, rib projections........	$C=14,000$, T not less than $\frac{7}{16}$ in.
Brown corrugated type...........	$C=14,000$, T not less than $\frac{5}{16}$ in.
Type having sections 18 ins. long..	$C=10,000$, T not less than $\frac{7}{16}$ in.

Limiting dimensions from center of the corrugations or projecting ribs, and of their depth, are given for each furnace.

Tube Spacing in Horizontal Tubular Boilers.—In modern practice the tubes are arranged in vertical and horizontal rows (not staggered as in earlier practice), with not less than 1 in. space between adjacent tubes, not less than 2 ins. between the two central vertical rows, and not less than $2\frac{1}{2}$ in. between the shell and the nearest tube. In boilers 60 in. diameter and larger a manhole is put in the front head beneath the central rows of tubes. Fig. 173 (from J. T. Ryerson & Son, Chicago) shows the arrangement of tubes and also of the braces in a 72 in. boiler.

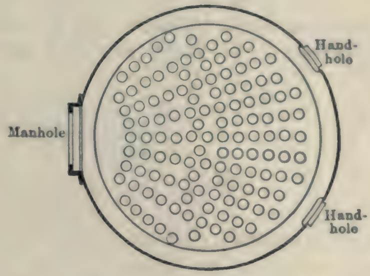

FIG. 174.—RADIAL ARRANGEMENT IN TUBES IN A VERTICAL BOILER.

Fig. 174 shows how the tubes are arranged in some styles of vertical tubular boiler in order to facilitate the cleaning of scale from the tubes and crown-sheet.

Manholes and Handholes.—Manholes are usually made 11x15 in.,

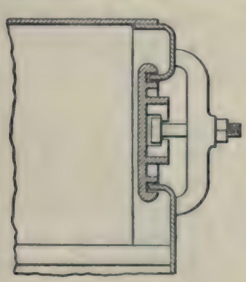

FIG. 175.—FLANGED MANHOLE.

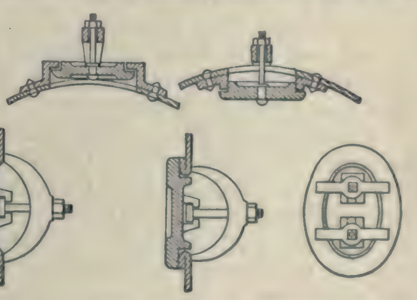

FIG. 176.—MANHOLE AND HANDHOLE PLATES.

of elliptical shape. The metal around them should be reinforced, either by riveting on it an elliptical ring, or by flanging. The

sectional area of the reinforcing ring should not be less than that of the portion of the plate removed in making the manhole, measured through its longer axis. Handholes are of the same shape as manholes, and are usually made about 4x6 in. They should always be reinforced. Various methods of reinforcing are shown in Figs. 175 and 176.

Rule for Reinforcing. (Hartford Steam Boiler Insurance and Inspection Co.)—To find the least allowable proportions of a reinforcing ring, multiply the thickness of the plate by the length of the stock-hole; this gives the sectional area of plate cut away in making the hole. The total sectional area of the reinforcing ring must be at least as great as this, and the material of the ring must be as good as the material of the shell plates. The width of the reinforcing ring is usually limited by circumstances, but when the width has been decided, the *thickness* of the ring may be determined as follows: If there are *two* rings, one inside and one outside as

FIG. 177.—RE-INFORECMENT OF MANHOLE.

we recommend, and as is shown in Fig. 177, the thickness of each ring is found by dividing the sectional area of the ring by four times its width. (If only *one* ring is used, its thickness must be equal to the combined thickness of the *two* rings shown in Fig. 177.

Rules of the United States Board of Supervising Inspectors: When holes exceeding six inches in diameter are cut in boilers for pipe connections, man and handhole plates, such holes shall be reinforced with wrought iron or steel rings of sufficient width and thickness of material to equal the amount of material cut from such boilers, except that when holes are cut in any flat surface of such boilers, and such holes are flanged inwardly to a depth of not less than 1½ inches, measuring from the outer surface, the reinforcement rings may be dispensed with.

Massachusetts Rule for Manholes.—A manhole shall be located in the front head, below the tubes, of a horizontal return-tubular boiler 60 in. or over in diameter. A manhole or handhole shall be located in the front head, below the tubes, of a horizontal return-tubular boiler less than 60 in. in diameter. A handhole shall be located in the rear head of a horizontal return-tubular boiler, below the tubes, except one which has a manhole in the front head, below the tubes.

Dimensions of Boilers.—The tables on pages 439 and 440 give the principal dimensions of standard forms of horizontal return-tubular boilers and of vertical tubular boilers.

Return-tubular Boilers. Standard Dimensions. (Coatesville Boiler Works.)

Number of Sizes.	Horse-power.	Diameter, inches.	Length, feet.	Thickness of Shell.	Thickness of Heads.	Number of 3-inch Tubes.	Weight of Bare Boiler, approx.	Weight of Castings, approx.	Height of Stack, feet.	Diameter of Stack, inches.	Thickness of Stack B. G. No.
1	15	36	8	1/4	3/8	26	2786	2700	30	14	16
2	20	36	10	1/4	3/8	26	3328	2700	30	14	16
3	25	42	10	1/4	3/8	36	4458	2900	30	16	16
4	30	44	10	9/32	3/8	42	4750	3500	40	18	16
5	35	44	12	9/32	3/8	42	5246	3700	40	18	16
6	40	44	14	9/32	3/8	42	5790	4000	40	18	16
7	40	48	12	5/16	7/16	48	6122	4300	40	18	16
8	45	48	14	5/16	7/16	48	6832	4300	40	20	16
9	50	48	16	5/16	7/16	48	7507	4400	40	20	16
10	55	54	12	5/16	7/16	64	8100	4500	40	23	16
11	60	54	14	5/16	7/16	64	8700	4600	40	23	16
12	70	54	16	5/16	7/16	64	10000	4800	50	23	14
13	60	60	12	11/32	7/16	82	9020	4900	45	26	10–12
14	70	60	14	11/32	7/16	82	10264	5000	45	26	10–12
15	80	60	16	11/32	7/16	82	11355	5100	50	26	10–12
16	95	60	18	11/32	7/16	82	12327	5300	60	26	10–12
17	90	66	14	3/8	1/2	98	12203	6200	50	28	10–12
18	100	66	16	3/8	1/2	98	13498	6400	55	28	10–12
19	125	66	18	3/8	1/2	98	14679	6600	60	28	10–12
20	100	72	14	7/16	1/2	120	15000	6900	50	32	10–12
21	125	72	16	7/16	1/2	120	16500	7100	60	32	10–12
22	150	72	18	7/16	1/2	120	17700	7300	60	32	10–12
23	175	72	20	7/16	1/2	120	19500	7500	60	36	10–12
24	175	78	18	7/16	9/16	....	20000	8000	60	36	10–12
25	200	78	20	7/16	9/16	....	22000	8200	60	36	10–12

Dimensions of Vertical Tubular Boilers.

Standard

Horse-power.	Shell. Diam.	Shell. Height.	Furnace. Diam.	Furnace. Height.	2-in. Tubes Length.	2-in. Tubes No.	Heating Surf.	Diam. Stack.
	in.	ft.	in.	in.	in.		sq.ft.	in.
4	24	4	20	24	24	31	44	12
5	24	5	20	24	36	31	60	12
6	24	6	20	24	48	31	75	12
8	30	5	25	27	33	55	92	14
10	30	6	25	27	45	55	121	14
12	30	7	25	27	57	55	150	14
15	36	6½	31	28	50	77	189	15
18	36	7	31	28	56	77	210	15
20	36	8	31	28	68	77	250	15
25	42	7¼	37	30	57	109	307	18
30	42	8¼	37	30	69	109	364	18
35	42	9¼	37	30	81	109	422	20
40	48	8½	43	32	70	149	496	24
45	48	9	43	32	76	149	535	24
50	48	10	43	32	88	149	613	24
60	54	9	48	32	76	201	716	28

Submerged Tube.

Horse-power.	Shell. Diam.	Shell. Height.	Furnace. Diam.	Furnace. Height.	2-in. Tubes. Length.	2-in. Tubes. No.	Height of Core.	Heating Surf.
	in.	ft.	in.	in.	in.		in.	sq.ft.
4	24	5½	20	24	24	31	18	44
5	24	6	20	24	30	31	18	52
6	24	6½	20	24	36	31	18	60
8	30	6	25	27	27	55	18	83
10	30	6½	25	27	33	55	18	98
12	36	6½	31	27	33	77	18	133
15	36	7	31	27	39	77	18	155
18	36	8	31	27	51	77	18	196
20	42	7½	37	27	39	109	24	215
25	42	8	37	27	45	109	24	244
30	48	9	43	27	57	109	24	301
35	48	9	43	30	51	149	27	370
40	48	9½	43	30	57	149	27	409
45	54	10	43	30	63	149	27	448
50	54	9½	48	30	54	201	30	518
60	54	10½	48	30	66	201	30	623

Standard Vertical Boilers. (Coatesville Boiler Works.)

Number of Sizes.	Horse-power.	Diameter of Boiler, ins.	Height of Boiler, ft.	Diameter of Fire Box, ins.	Height of Fire Box, ins.	Number of Tubes.	Diameter of Tubes.	Length of Tubes, ins.	Heating surface, sq.ft.	Thickness of Shell.	Thickness of Head.	Approx. Weight, bare Boiler.	Approx. Wt. with Fixtures.	Price, bare Boiler.	Price, Boiler, Base, Grates and Hood.	Price, Boiler, Base, Grates, Hood and Fittings.	Price of Stack per foot, No. 16 Iron.
1	3½	24	4	20	22	30	2	26	45	1/4	3/8	800	1100	$100	$120	$140	$1.40
2	5	24	5	20	22	30	2	38	60	1/4	3/8	925	1225	112	133	153	1.40
3	6½	24	6	20	22	30	2	50	76	1/4	3/8	1050	1375	126	147	167	1.40
4	7	30	5	25	27	48	2	33	86	1/4	3/8	1350	1825	147	174	196	1.60
5	9	30	6	25	27	48	2	45	111	1/4	3/8	1525	2000	166	194	215	1.60
6	11	30	7	25	27	48	2	57	136	1/4	3/8	1725	2200	191	218	240	1.60
7	13	30	8	25	27	48	2	69	161	1/4	3/8	1925	2400	209	236	258	1.60
8	12	36	6	31	27	66	2	45	151	9/32	3/8	2025	2675	217	254	277	1.80
9	15	36	7	31	27	66	2	57	185	9/32	3/8	2300	2950	247	275	297	1.80
10	18	36	8	31	27	66	2	69	220	9/32	3/8	2575	3225	281	308	331	1.80
11	20	42	7	37	30	90	2	54	241	5/16	3/8	2850	3775	308	358	384	2.10
12	24	42	8	37	30	90	2	66	288	5/16	3/8	3225	4150	345	394	420	2.10
13	28	42	9	37	30	90	2	78	334	5/16	3/8	3575	4500	382	432	457	2.10
14	32	42	10	37	30	90	2	90	381	5/16	3/8	3825	4750	421	460	496	2.10
15	33	48	8	43	30	124	2	66	391	5/16	7/16	4125	5375	442	510	536	2.40
16	38	48	9	43	30	124	2	78	455	5/16	7/16	4650	5900	481	550	575	2.40
17	43	48	10	43	30	124	2	90	520	5/16	7/16	4975	6225	540	608	634	2.40
18	48	48	11	43	30	124	2	102	584	5/16	7/16	5450	6700	590	658	684	2.40
19	50	54	10	49	31	148	2	89	609	11/32	7/16	5925	7400	617	681	712	2.75
20	57	54	11	49	31	148	2	101	686	11/32	7/16	6450	7925	675	739	770	2.75

Fittings comprise one steam gage, three gage cocks, one glass water gage, one safety valve, one check valve, one blow-off cock. All boilers are tested to 150 pounds, hydrostatic pressure. Discounts on application.

Dimensions of Marine Water-tube Boilers.—The following table of the weight and space occupied by various makes of marine water-

Number	Kind of Boilers.	Heating Surface. sq.ft.	Length. ft.	in.	Width. ft.	in.	Height. ft.	in.	Outside Diameter of Tubes. in.
1	Babcock & Wilcox (U.S.S. Utah) 8 ft. tubes	5359	9	1	18	4	13	11	2 & 4
2	Babcock & Wilcox (U.S.S. New Hampshire) 9 ft. tubes	3926	10	1	14	10	13	2	2 & 4
3	Normand (T.B.D. Trippe)	4780	12	6	15	1	14	2	1 & 1⅛
4	Normand, modified (U.S.S. Salem)	3166	9	11	12	0	12	2	1⅛
5	Normand, modified (U.S.S. Chester)	2670	10	8	12	8	11	10	1⅝
6	Mosher (U.S.S. Kearsarge)	3980	12	2	15	2	12	9	2
7	Thornycroft (T.B.D. Terry)	4500	10	9	15	3	12	2	1⅛ & 1⅜
8	White-Forster (T.B.D. Maryant)	4500	9	1	14	8	12	8	1 & 1⅛
9	Yarrow (T.B.D. Sterrett)	4500	12	9	14	2	12	10	1 & 1¼
10	Thornycroft (T.B.D. Burrows)	4800	12	7	15	3	12	6	1⅛ & 1⅜

Number.	Kind of Boiler.	Gage of Tubes. B. W. G. No.	Floor Space. sq. ft.	Cubic Space. cu. ft.	Sq. ft. of H. S. per sq. ft. of Floor Space.	Sq. ft. of H. S. per cu. ft. of Cubic Space.	Weight of boiler and water per sq. ft. H. S. pounds.
1	Babcock & Wilcox (U.S.S. Utah) 8 ft. tubes	8 & 6	167.7	2337	31.96	2.293	*28.70
2	Babcock & Wilcox (U.S.S. New Hampshire) 9 ft. tubes	8 & 6	150.0	1978	26.18	1.985	*25.80
3	Normand (T.B.D. Trippe)	12 & 10	188.6	2672	25.35	1.789	†12.40
4	Normand, modified (U.S.S. Salem)	11	119.4	1453	26.51	2.179	*13.10
5	Normand, modified (U.S.S. Chester)	10	134.7	1592	19.82	1.678	*17.64
6	Mosher (U.S.S. Kearsarge)	8	184.2	2349	21.60	1.695	*23.00
7	Thornycroft (T.B.D. Terry)	12 & 10	164.3	1997	27.31	2.254	†12.20
8	White-Forster (T.B.D. Maryant)	12 & 10	133.3	1688	33.74	2.665	†12.10
9	Yarrow (T.B.D. Sterrett)	12 & 10	181.0	2323	24.86	1.937	†12.50
10	Thornycroft (T.B.D. Burrows)	11 & 10	192.9	2422	24.88	1.982	†13.23

* Includes grates—coal burning. † No grates—oil burning.
Weights are for boilers and fittings with water, and do *not* include uptakes and funnels.

tube boilers is given by Rear-admiral G. W. Melville, U. S. N. (*Eng. Mag.*, Jan., 1912).

Sizes of Water-tube Boilers.—Water-tube boilers are commonly made with 4-in. tubes; some, such as the Heine boiler, are made with 3½-in., and the Babcock & Wilcox marine type are made with the bottom row 4-in. and all the others 2-in. tubes. The length, number, spacing and arrangement of the tubes vary greatly according to the style of boiler and the size and shape of the space it is designed to occupy. In calculating the heating surface of a water-tube boiler of the ordinary types, with straight tubes, the following table will be found convenient:

HEATING SURFACE OF BOILER TUBES, 2, 3½ AND 4-IN. DIAMETER.

Diam. of Tubes in.	Length of Tubes, Feet.						
	8	10	12	14	16	18	20
	Heating Surface of One Tube, Sq.ft.						
2	4.189	5.236	6.283	7.330	8.378	9.425	10.472
3½	7.330	9.163	10.996	18.828	14.661	16.493	18.326
4	8.378	10.472	12.566	14.661	16.755	18.850	20.944

In the standard form of inclined tube boiler, with 4-in. tubes, the length of the tubes is commonly made 18 ft., and the number of tubes in a horizontal row, according to the size of the boiler, is 4, 5, 6 or 7 with one longitudinal steam and water drum, 8, 10, 12 or

14 with two drums, and 21 with three drums. The number of horizontal rows is 7, 8, 9, 10, 12 or 14. The number of tubes and the total heating surface of the tubes in these arrangements, together with the corresponding area of grate surface, are given below:

HEATING SURFACE OF WATER-TUBE BOILERS.

Tubes High.	Number of Tubes Wide.								
	4	5	6	7	8	10	12	14	21
	Total Number of Tubes.								
7	28	35	42	49	56	70	84	98	147
8	32	40	48	56	64	80	96	112	168
9	36	45	54	63	72	90	108	126	189
10	40	50	60	70	80	100	120	140	210
12	48	60	72	84	96	120	144	168	252
14	56	70	84	98	112	140	168	196	294
	Total Heating Surface, with Tubes 18 Feet Long.								
7	528	660	792	924	1056	1319	1583	1847	2771
8	604	754	905	1056	1206	1508	1810	2111	3167
9	690	848	1018	1188	1357	1696	2036	2375	3563
10	754	942	1131	1319	1508	1885	2262	2639	3958
12	905	1131	1357	1583	1810	2262	2714	3166	4750
14	1056	1319	1583	1847	2111	2639	3167	3694	5542
	Grate Surface, 7 Feet Long, Square Feet.								
	16.3	20.4	24.5	28.6	32.7	40.8	49.0	57.2	85.7

The water and steam drums are usually made 30, 36, 42 or 48 in. diameter, and of lengths ranging from 6 to 20 ft., according to the size of the boiler and according to whether the drum is placed lengthwise or crosswise of the boiler. Taking the heating surface as that of the lower half of the drum, the following table gives the heating surface of drum of the several sizes named:

Length, ft.	6	8	10	12	14	16	18	20
Diam., ins.	Heating Surface of Lower Half of Drum, sq.ft.							
30	24	31	39	47	55	63	71	79
36	28	38	47	57	66	75	85	94
42	33	44	55	66	77	88	99	110
48	38	50	63	75	88	101	113	126

Specifications for Horizontal Tubular Boiler and Boiler-room Equipment. (Charles L. Hubbard, in *Power,* Dec. 1905.)—The appended "dummy" has been found useful in making up specifications for tubular boilers, together with their settings. Under each heading will be found numbered clauses to fit all usual cases, and such of these may be chosen as are necessary to meet the conditions of any

particular instance. For example, under "Braces," No. 1 calls for the usual crowfoot bracing; Nos. 3 and 4, or 3 and 5, call for through-bracing, and Nos. 1, 2 and 4 a combination of the two.

In making up a specification the engineer has simply to check off the clauses he wishes to use under the different heads, fill in with pencil the spaces left for dimensions, etc., and his typewriter operator may do the rest. Check marks and writing can be erased afterward, and the dummy used again and again a number of times.

Blank spaces are filled in, in the following specification, in order to make the method of use more clearly understood.

Specifications for Boilers.

Type and General Dimensions.—The boilers, 2 in number, are to be of the horizontal tubular type, with full overhanging fronts, and all parts and pieces must be designed accordingly.

The shells are to be 16 feet 6 inches long outside, and 60 inches in diameter, measured on the outside of the smallest ring of plates.

The heads are to be 15 feet 0 inches apart outside. The size and description of the other parts are to conform substantially to the details usually furnished by the Inspection and Insurance Company for boilers of this size, and during the process of construction all the material and workmanship entering into the same are to be subjected to the inspection of the engineer and a representative of said company.

Materials; Quality and Thickness.—(1) Shell plates are to be 3/8 of an inch in thickness, of open-hearth fire-box steel, having a tensile strength of not less than 54,000 nor more than 60,000 pounds per square inch, with not less than 56 per cent as contraction of area, and an elongation of 25 per cent in length of 8 inches.

(2) Phosphorus to be less than 0.03 per cent and sulphur less than 0.025 per cent.*

(3) A coupon two inches wide is to stand bending 180 degrees on itself without showing signs of fracture, both before and after heating to a cherry-red and quenching in water.

(4) A sworn certificate is to be furnished by the plate mill that each heat of metal used for the plates has been tested and fulfilled the chemical tests, and that the coupon from each plate has been tested and has come up to the physical requirements. With and as a part of the certificate shall be furnished a schedule of the samples tested and the data determined by the tests.

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* The Hartford Steam Boiler Inspection and Insurance Co. allows 0.035 phosphorus and 0.035 sulphur. The Pennsylvania Railroad Co.'s specifications for fire-box steel allow 0.035 P and 0.003 S. American Bureau of Shipping's specifications for marine boilers allow for shells P and S each not over 0.04; for fire-boxes, P and S each not over 0.035.

(5) Heads to be ½ inch in thickness of best open-hearth flange steel.

(6) All plates, both of shells and heads are to be plainly stamped with the name of maker, brand and tensile strength. The marks shall be so located that they may be plainly seen on each plate after the boiler is constructed.

Riveting.—(1) Longitudinal seams are to be of the double-riveted lap-joint type with rivets staggered.* They must be arranged to come well above the fire line of the boilers, and must break joints in different courses in the usual manner.

Rivets to be 13-16 inch in diameter and pitched 3 inches on centers; the two rows to be 2 inches apart on centers.

(2) Longitudinal seams are to be of the double-riveted butt-joint type with double covering strips. They must be arranged to come well above the fire line of the boilers, and must break joints in different courses in the usual manner.

Rivets are to be ¾ inch in diameter; those of the inner rows are to be pitched 2 inches apart.

The rivets of the outer rows are to be pitched 4 inches on centers and the rows to be $2\frac{1}{2}$ inches apart.

The covering strips are to be ⅜ inches in thickness.

(3) Longitudinal seams are to be of the triple-riveted butt-joint type with double covering strips. They must be arranged to come well above the fire line of the boilers, and must break joint in different courses in the usual manner. Rivets are to be ¾ inch in diameter; those of the two inner rows are to be pitched $3\frac{1}{8}$ inches on centers, and the rows are to be $2\frac{1}{2}$ inches apart; the rivets of the two intermediate rows are to be pitched $3\frac{1}{8}$ inches on centers and the rows are to be $6\frac{3}{4}$. inches apart, while the rivets of the two outer rows are to be pitched $6\frac{1}{4}$ inches, and the rows are to be $11\frac{3}{4}$ inches apart. The covering strips are to be 5-16 inch in thickness.

(4) The transverse seams are to be single riveted, with rivets 13-16 inch in diameter and pitched 2 inches on centers.

(5) The rivet holes must be drilled, and must be neatly chamfered 1-32 inch on the faying side of all plates. Care must be exercised in drilling the holes that they come fair in construction.

(6) The use of the drift pin to bring blind or partially blind holes in line will be sufficient cause for the rejection of the boilers.

Braces.—(1) Each boiler shall have 8 solid steel crowfoot braces attached to each head above the tubes and arranged as shown on detail. Each brace shall have a sectional area of not less than 1 square inch at its weakest part, and shall be riveted to the head and shell with two 1 inch rivets at each end.

Braces in the outer row shall be 48 inches in length, those

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* The lap joint for longitudinal seams is now condemned by law in some States.

in the second row 60 inches in length, and those in the third row 72 inches in length. Care must be exercised in setting them so that they shall bear a uniform tension.

(2) In addition to the crowfoot braces above specified, each boiler shall have 3 through braces of mild steel of a tensile strength equal to that of the shell.

Each brace shall be $1\frac{1}{2}$ inches in diameter and without welds. The ends shall be upset to 2 inches and shall be provided with nut, check-nut and heavy cast-iron washer, one inch in thickness and 5 inches in diameter, planed or milled on both sides.

(3) Each boiler shall have 5 through braces of mild steel of a tensile strength equal to that of the shell.

Each brace shall be $1\frac{1}{2}$ inches in diameter and without welds. The ends shall be upset to 2 inches and shall be provided with nut, check-nut and heavy cast-iron washer, one inch in thickness and 5 inches in diameter, planed or milled on both sides.

Care must be exercised in setting them, so that they shall bear uniform tension.

(4) The boiler heads are to be stiffened with 6 inch by 2.39 inch by 0.52 inch channel bars riveted to the heads and arranged as shown on detail.

(5) The boiler heads are to be stiffened with 3 inch by 3 inch by $\frac{1}{2}$ inch angle bars riveted to the heads and arranged as shown on detail.

Tubes: (1) Each boiler is to have 72 best lap-welded tubes 3 inches in diameter and 15 feet long, set in vertical and horizontal rows, with a clear space between them vertically and horizontally of one inch, except the central vertical space, which is to be 2 inches.

The holes for the tubes are to be neatly chamfered off on the outside.

(2) The tubes are to be set with a expander and beaded down at each end.

Manhole: Each boiler is to have one manhole, 11x15 inches, with a strong internal frame, made of "gun" iron or sound steel casting, with suitable plate, yoke and bolt, the proportions of the whole to be such as will make it as strong as any portion of the shell of like area. It is to be located in the shell on top of boiler.

Handholes: Each boiler is to have one handhole, 4x6 inches, with suitable plate, yoke and bolt, located in each head, below the tubes.

Brackets and Wall Plates: (1) Each boiler is to have 4 cast-iron brackets, 2 on each side, securely riveted in place, 12 inches long, with a projection of 10 inches from the shell.

(2) Cast-iron wall plates 20 inches long, and 10 inches wide and $1\frac{1}{2}$ inches thick shall be furnished for each bracket to rest upon, and three rollers 1 inch in diameter and 9 inches

long shall be furnished for all except the front brackets, to rest upon to allow free expansion of the boiler.

Nozzles.—Each boiler is to have two nozzles of "gun" iron or cast steel, 5 inches in diameter for steam-pipe connection, and one 4 inches in diameter for safety-valve connection, each accurately squared on top flange, and securely riveted to the boiler. These flanges are to be trued to the plane of the tubes, and must receive the approval of the engineer in this regard before the boilers are set.

Smoke Opening.—Each boiler is to have an opening 12 inches by 38 inches cut out of front connection (on top) for the attachment of uptake or bonnet.

Internal Feed Pipe.—Each boiler is to have a hole tapped to receive a $1\frac{1}{4}$ inch feed-pipe. This is to be located at the front head at the point indicated on details; also furnish and put in a $1\frac{1}{4}$ inch brass feed-pipe, extending from front head back to within two feet of the rear head of the boiler, thence across the end to an elbow looking down between the tubes and shell. The pipe shall be securely supported by hangers attached to the braces.

Blow-off.—(1) Each boiler is to have a circular plate of the same material as the shell, 8 inches in diameter and five-eighths inch thick, riveted to the bottom of the shell, 9 inches from the back end, and tapped to receive a 2 inch blow-off pipe.

(2) The blow-off pipes are to be extra heavy, with extra heavy fittings, and are to be carried straight down through the paving of the combustion chamber. That portion exposed in the combustion chamber is to be protected by a cast-iron sleeve packed with mineral wool.

(3) These pipes are to be extra heavy, with extra heavy fittings, and are to be carried straight down through the paving of the combustion chamber; they are to be protected on the side toward the furnace by means of a V-shaped shield of fire-brick laid in either a mixture of fire-clay and ground fire-brick, or in pure cement, and extending from the paving to the boiler shell.

Fusible Plug.—The boilers are each to be provided with a high-pressure, long fusible plug in the back head with its center two inches above the top of the upper row of tubes.

Fittings.—(1) Furnish and properly connect to each boiler one 8 inch steam gage with nickel-plate rim and iron body of the or other approved make, graduated for indicating pressures up to a maximum of 100 pounds per square inch.

(2) Furnish and connect to each boiler one $3\frac{1}{2}$ inch or other equally approved make, pop safety valve, set to blow at a pressure of 70 pounds per square inch.

(3) Furnish and connect with each boiler one 4 inch or other equally approved lever safety valve of best make, and set to blow at a pressure of 70 pounds.

(4) Provide suitable chain and pulley attachments for lifting

the safety valves and carry the pull chains to such convenient point for use, as shall be directed by the engineer.

(5) Connect each safety valve with a 3½ inch pipe and carry the same out-of-doors, as directed for discharge.

(6) This pipe is to be dripped to the ash-pit through a ¾ inch connection if found necessary by the engineer.

(7) Furnish and connect with each boiler one combination box with a ¾ inch gage glass, and three gage cocks; the boiler connections are to be of 1¼ inch brass pipe outside the smoke bonnet and extra heavy wrought iron of the same size inside the bonnet. A ¾ inch brass drip pipe with valve is to be carried to the ash-pit.

Set the water gage at such a level that there shall be two inches of water over the top of the tubes when the water disappears from the bottom of the glass.

Castings, Doors, Bolts, etc.—(1) Each boiler shall be provided with a cast-iron front, neatly made and close fitting, and erected in strict accordance with directions to be given by the engineer; all necessary anchor bolts 10 feet long; close-fitting front connection doors, with suitable fastenings to prevent warping; 2 furnace doors with liner plates; 2 ash doors; back connection door, 16x24 inches, with liner plates; all doors to be made easily closing and tight fitting.

(2) Arch bars for back connection and all buckstaves, with the necessary bolts or tie-rods; and all other castings or iron work of any description necessary for the proper setting of the boilers complete.

Grates.—(1) Provide and install grate-bars for plain grates of the , or other approved pattern, 60 inches long by 54 inches wide with suitable bearer bars for the same.

(2) Provide and install complete for operation, shaking grates of the , , or other approved make, 60 inches long by 54 inches wide.

Inspection and Insurance.—The size and description of all parts to conform subtantially to the details usually furnished for boilers of this size, and during the process of construction all the material and workmanship are to be subject to the inspection of, and after erecting to be approved by, the engineer and by the Inspection and Insurance Company, and the latter's insurance policy for $1000 on each boiler for 3 years from completion of setting to be furnished the owners by the contractor.

Tests.—Before leaving the construction shops, each boiler shall be tested under a hydrostatic pressure of 150 pounds to the square inch, and all joints and all connections made tight at that pressure.

Should leaks develop under pressure when first applied, the pressure shall be removed and all leaks stopped by calking, after which the boiler must again be subjected with satisfactory results to the pressure.

All tests shall be made in the presence of a representative of the aforesaid insurance company and of the engineer.

Boiler Foundations.—(1) The boiler foundations will be furnished under another contract.

(2) The boiler foundations are to be furnished by the contractor, and shall be of concrete or of stone, laid in pure cement. If concrete is used, it shall consist of one part best Portland cement, two parts of clean, sharp sand and four parts of broken stone. They shall extend a distance of not less than 30 inches below the boiler-room grade, or shall be carried to such depth as the engineer shall direct in order to secure a proper footing.

(3) The width of foundation for the different walls of the setting shall be as follows: Outside walls, 42 inches; division walls 4 inches; front wall, 24 inches; bridge wall, 24 inches; rear wall, 42 inches.

(4) The foundation shall be in the form of a solid bed, 20 feet, 0 inches long, by 18 feet 10 inches wide, and of the depth specified above.

Boiler Settings.—(1) The boiler settings are to be built substantially, as shown on plans.

(2) The settings are to be of the usual form employed for this type of boiler.

(3) Inside bricks are to be light-hard; exposed or outside bricks are to be best quality hard-burned.

(4) Furnace, bridge wall and combustion chamber are to be lined with A1 firebrick.

(5) Furnace, bridge wall and arch over combustion chamber are to be lined with A1 fire-brick.

(6) The outside walls are to be 22 inches in thickness, made up of a 12 inch inside wall, a 2 inch air-space, and an 8 inch outside wall; division wall, 2 inches; front wall, 9 inches; bridge wall, 24 inches; and rear wall, 18 inches, made up of two 8-inch walls, with a 2-inch air-space between. The distance from bridge wall to boiler shell shall be 9 inches.

(7) All red bricks are to be laid in cement mortar of best quality, mixed the day it is to be used. Fire-bricks are to be laid either in a mixture of fire-clay and ground fire-brick, or in pure cement, with very close joints.

(8) The boiler tops are to be covered with one layer of light-burned brick, laid loose on side, care being taken to leave a clear space about the rivet heads, and an outer cover similarly laid in cement mortar.

(9) The entire surface of the boiler setting is to be covered with two coats of freshly made cement wash, colored to resemble brick and applied with a brush. This wash is to be applied near the completion of the contract, and, before it is done, all cracks and openings in the setting shall be pointed. If any portion of the setting has become loosened by the expansion of the boilers it shall

be removed and the bricks relaid in a manner satisfactory to the engineer.

Smoke Connection.—(1) Smoke connections are to be made of No. 12 American gage black iron of the sizes indicated, and are to be run as shown on plans. So far as practicable, all rectangular parts are to be made with internal angle irons, to which the plates are to be riveted, and all joints are to be made tight with suitable filling, if found necessary.

All joints between boilers and uptakes are to be neatly and tightly made by means of angles bolted to the shells and uptakes. Clean-out doors are to be provided as indicated or directed.

(2) A damper is to be placed in each uptake or bonnet for hand regulation, and suitable and approved means are to be approved for adjusting and securing it in any desired position.

(3) Furnish and place in the main smoke-pipe a balanced damper of No. 10 iron, closing at an angle of 45 degrees, and provide the same with roller bearings for easy movement. This damper is to be connected with a damper regulator to be specified later.

Damper Regulator.—Furnish and properly connect to the steam main, water pressure and main damper a , , or other approved damper regulator of latest pattern, locating the same in the boiler-room at such point as the engineer shall direct. Provide all necessary chains, weights and pulleys and adjust the regulator to close the damper at a pressure of 50 pounds steam pressure.

Feed Pipe.—(1) The feed pipe to the boilers should be of brass, 1½ inches in diameter, each branch to be furnished with a check valve and gate valve, placed inside the check next to the boiler. A 1½ inch brass connection shall be made between this pipe and the supply main inside the building.

(2) The delivery pipe from the pumps to the boilers shall be 2 inches in diameter, of heavy polished brass, with polished brass fittings, and run substantially as shown on plans. Each branch is to be furnished with a check valve, finished brass union, and gate valve placed inside the check next to the boiler.

That portion of the feed pipe within the smoke bonnets is to be of extra-heavy iron. A 1½ inch valved connection of brass pipe is to be made with the feed pipe between the pumps and boiler for supplying water directly from the street main.

Blow-off Pipe.—(1) Provide and place in the blow-off pipe from each boiler an asbestos-packed cock, a gate valve and flanged union, placing the gate valve inside the cock next to the boiler. Provide wrenches for the cocks.

(2) Provide and place in the blow-off pipe from each boiler a heavy blow-off valve, made by ; also a heavy flanged union.

Blow-off Tank.—(1) Furnish, place and connect, in a complete and proper manner, a blow-off tank of ¼ inch boiler iron, heads to be 5-16 inch in thickness and of the same material. The tank

shall be 36 inches in diameter by 48 inches in length; it shall be made with a manhole on top and a handhole in each end, each to be furnished with a suitable plate, yoke and bolt. Provide with drain from the bottom and inlet at the top, so designed as to keep the tank continuously full of water. It is to be mounted on cast- or wrought-iron cradles, bolted to bluestone or slate slabs, mounted on brick foundations.

Provide and connect with the tank a 24 inch water-gage glass.

(2) Furnish, place and connect in a complete and suitable manner a cast-iron flow-off tank, 24 inches in diameter by 48 inches in depth. The tank is to have a cast-iron head and is to be furnished with a suitable drain from the bottom and inlet at the top, so designed as to keep it continuously full of water. The tank is to be sunk in the ground to a depth of 40 inches.

Fire Tools.—Furnish complete sets of fire tools, each consisting of slice-bar, poker, hoe, steam-jet flue cleaner, large-size steel scoop shovel, long-handled shovel and long wooden-handled hoe of large size for removing ashes. Provide iron racks of approved design for holding the tools when not in use.

(3) Furnish one coal barrow of 300 pounds capacity, made by and of a pattern approved by the engineer.

(4) Furnish one steel coal car of 500 pounds capacity, made by and of a pattern approved by the engineer.

(5) Furnish one 50 foot length of best $\frac{3}{4}$ inch 4-ply rubber hose, complete with coupling, nozzle, etc. It is to be furnished and mounted on an iron hose rack in the boiler-room. Also provide screw bibbs in the water-supply pipe at convenient points for the attachment and use of the hose.

Feed Pumps.—(1) Furnish 2 duplex, brass-finished boiler feed pumps, $4\frac{1}{2}$ by $2\frac{3}{4}$ by 4 inches in size, of , , or other approved make of equal capacity. Mount the pumps on brick foundations, capped with bluestone or slate slabs of suitable size. Make all steam exhaust, suction and discharge connections, connect all drips with the sewer, and provide all valve and fittings required for installing the pumps in a complete and satisfactory manner, ready for use. Provide and connect with the steam pipe of each pump a or other approved, brass sight-feed lubricator of 1 pint capacity.

(2) Suitable pans of heavy copper, of a size to accommodate the bed plates of the pumps, are to be provided for catching the leakage of water and oil. These are to be dripped to the sewer through valved drain pipes of suitable size.

(3) The cast-iron bed plates of the pumps are to be so made as to form a drip pan for catching the leakage of water and oil. These are to be dripped to the sewer through valved drain pipes of suitable size.

The specifications of Mr. Hubbard agree fairly well with the printed specifications issued by the largest manufacturers and with those of the boiler inspection and insurance companies. The specifications of the Bigelow Co., New Haven, Conn., contain some items not included in Mr. Hubbard's specifications, and also some differences of detail, such as quality of rivets, machine-flanging and annealing of heads, and pressed steel manhole frames. Some paragraphs from the Bigelow Co.'s specifications are given below.

Riveting.—All holes to be punched 1/8 of an inch smaller than the diameter of the rivet, where the plates are to be bolted together, and each and every rivet hole drilled in place, 1-16 of an inch larger than the diameter of the rivet. No rivets to be driven into unfair holes. Should any holes be in the least unfair, they are to be brought in line by the use of a reamer or drill, and in no case will a drift pin be used for this purpose. All rivets, where possible, to be driven by hydraulic pressure, and the rivet allowed to cool and take its shrinkage under pressure.

Rivets.—To be of soft steel, having tensile strength of not less than 52,000 pounds per square inch of section, and elongation of not less than 29 per cent in 8 inches.

Flanging.—Heads to be machine flanged, with a radius of 2½ inches, and after they have been bored and reamed for tubes and rivets are to be put into the furnace and thoroughly annealed.

Planing and Calking.—All plates to have proper allowance for planing, and to be planed on a planing machine to an angle of about 15 degrees from the vertical. The heads, after they have been flanged, drilled and annealed, are to be put on a boring mill and edges planed to the same bevel as the shell plates.

All seams to be carefully calked with a round nosed tool.

Holes for Tubes.—To be drilled and reamed not to exceed 1-32 of an inch larger than the diameter of the tube, and neatly chamfered on the outside. Tubes set with a Dudgeon expander, on each end.

Manholes.—Boiler to have a manhole opening 11 inches by 15 inches, with a double riveted internal pressed steel frame located on top of shell, with a suitable pressed steel plate with yoke and bolt nicely fitted, the proportions of the whole such as will make it equally as strong as any other portion of the shell, of like area.

Front and Castings for Setting.—Each boiler to be provided with a cast-iron front like Plate in our catalogue, made in not less than pieces, exclusive of the doors, fitted and fastened together with angle iron. To have double flue, fire and ash doors all closely fitted, with suitable fastenings to prevent warping, and the fire-doors to have liner plates bolted on. Front to have all necessary anchor bolts feet

long, also extra heavy arch and flat plate for top and bottom of fire-doors.

Arch plate to be of our special pattern, with removable fire-brick lining which can be replaced at any time without removing the cast-iron plate itself or affecting the mason work in any way whatsoever. Also special fire-brick jambs for the side of fire-doors.

One back cleaning door 18 inches by 20 inches, with tee pieces and anchor bolts to hold the same in the brick-work.

Three special patent rear arch bars for back connection, made to be lined with fire-brick.

Setting of a Horizontal Return-tubular Boiler.—Fig. 178 shows a modern form of setting of a return-tubular boiler, from a design described by S. F. Jeter (*Power,* Jan. 3, 1911). The following is condensed from his description: A good foundation should be prepared before the arrival of the boiler. The manufacturer of the

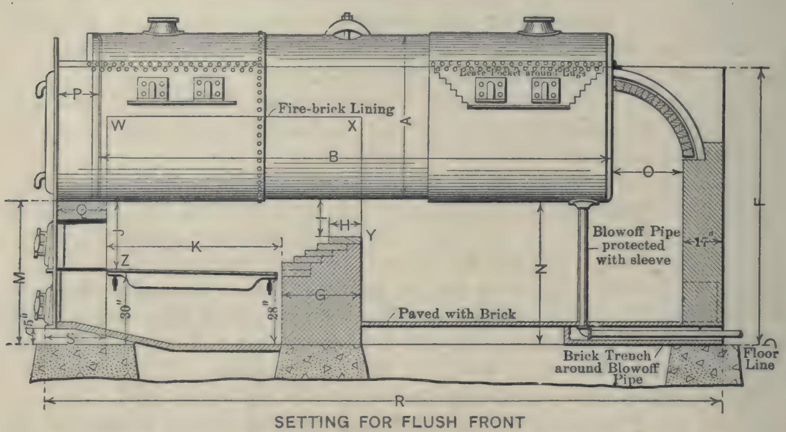

FIG. 178.—SETTING OF A HORIZONTAL RETURN-TUBULAR BOILER, FLUSH FRONT.

boiler should furnish a plan of the setting walls, and from this the dimensions and location of the foundation walls may be obtained. If a setting plan is not furnished, dimensions may be obtained from the table. The depth of foundations and the width of footings necessary depend upon the nature of the soil at each plant. Where the soil is capable of supporting only light loads, a bed of concrete, properly reinforced and extending entirely over the space occupied by the setting, makes a satisfactory foundation. For boilers supported on columns, the load on the portions of the foundations beneath the columns is more concentrated than in the case of lug-supported boilers resting directly on the brick-work, and it is necessary that additional width to the footings be provided at the base of the columns. The foundation must be capable of holding the boiler and setting practically rigid. A weak foundation will cause the

walls to crack and also may cause stresses on the pipe connections to the boiler that are apt to result in a serious accident.

When the boiler arrives at is destination it should be carefully unloaded and transported to the site of erection. The nozzles are most likely to be damaged in handling; and pipes or bars should never be stuck in the tubes to aid in moving the boiler.

It is best to place a boiler in the correct position with the front in place before commencing the brick-work; if the boiler is to be supported on lugs resting on the brick-work it should be placed about a half inch higher than the desired final position, to allow for lowering on the brick-work when the supports are removed. When a boiler is to be hung from beams it can be placed in the correct position at once. None of the weight should be carried by the boiler front, and to insure against this, ½ to ¾ inch clearance should be left between the bottom of the shell and the front. Ample clearance between the front and shell is especially important in the lug-supported type in order to allow for settling.

The front end of a boiler should be placed about one inch higher than the rear to aid draining through the blow-off pipe when washing out.

A mortar of lime and cement should be used in building boiler settings. Regular lime mortar is made, using three-quarters of a cubic yard of good, sharp sand to one barrel of lime, then a mixture of sand and cement is made, using two barrels of sand to four bags of cement added to the lime mortar. This quantity of material should make enough mortar to lay about one thousand brick. If all the mortar cannot be used at once, the sand and cement mixture should only be added to such portion of the lime mortar as will be required for immediate use, as it is difficult to keep it in proper condition over night after the cement has been added. Fire clay is the only bonding material that should be used in laying the fire-brick and for this purpose it should be mixed with water to about the consistency of buttermilk, so that the bricks may be dipped in it and rubbed together when laying them. About two barrels of fire clay are required to lay one thousand brick.

The temperatures attained in the furnaces of return-tubular boilers are generally moderate, and it does not require a specially high grade of fire-brick to withstand the heat; but there is more need of mechanical strength to withstand the wear incidental to the rubbing of the fire tools and breaking off clinkers. On this account a medium grade of fire-brick, costing about $22 to $25 per thousand, will be generally found most suitable. Fire-brick that are made especially with a view to resisting the very high temperatures are usually mechanically weak and soft and they are also the most costly. For arches in Dutch ovens, where there is no danger of hitting the brick with the fire tools, the higher grade of brick generally gives the best service. The common brick used for setting should be well burned.

DIMENSIONS FOR BOILER SETTING.

Horsepower on a Basis of 10 Sq.ft. of Heating Surface per Horsepower. 3-inch Tubes.	3½-inch Tubes.	4-inch Tubes.	Diameter of boiler. Inches. *A*	Length of Tubes, Feet. *B*	Number of Tubes.	Over-all width of Setting. *E*	Top of grates at Front to under Side of Shell, Ins. *J*	Length of Furnace, Ins. *K*	Width of Furnace, Ins. *L*	Approx. weight of Boiler and Water with Piping and Brick Covering on Top of Shell and Flue, Lbs.	Number of fire-bricks required to Set one Boiler.	Number of Red Bricks required to Set one Boiler.
53	48	44	48	12	50–3″ 38–3½″ 30–4″	8′–0″	26	48	42	16,000	800	13,500
61	56	51	48	14		8′–0″	26	54	42	18,000	850	15,000
72	63	51	54	14	60–3″ 44–3½″ 30–4″	8′–6″	28	54	48	23,000	950	16.500
83	72	58	54	16		8′–6″	28	54	48	25,500	950	18,000
99	88	86	60	16	72–3″ 54–3½″ 46–4″	9′–0″	28	60	54	32,500	1,100	18,500
110	99	96	60	18		9′–0″	28	66	54	35,500	1,150	20,000
130	118	108	66	16	98–3″ 74–3½″ 60–4″	9′–6″	30	72	60	38,000	1,350	20,000
147	132	121	66	18		9′–6″	30	78	60	41,500	1,400	22,000
163	149	131	72	16	124–3″ 96–3½″ 74–4″ ?	10′–9′	30	72	66	47,500	1,550	25,000
183	167	147	72	18		10′–9″	30	84	66	51,000	1,600	27,500
203	185	164	72	20		10′–9″	30	90	66	56,000	1,650	29,500
188	175	161	78	16	144–3″ 114–3½″ 92–4″	11′–3″	34	72	72	50,000	1,700	27,000
211	197	181	78	18		11′–3″	34	78	72	54,500	1,750	29,500
234	218	201	78	20		11′–3″	34	84	72	59,000	1,800	31,500

NOTE.—In using this table for setting boilers, dimensions *F*, *J*, *M*, and *N* must conform to the dimensions of the front furnished with the boiler and dimensions *K* and *L* with the grates furnished. On flush fronts, dimensions *Q*, *R*, and *S* depend on the dimensions *P*, and these dimensions must be changed to conform to any changes that may be necessary in *P*. The column giving the number of common brick required refers to the overhanging-front style of setting, and for flush fronts there should be added 500 to 2500 brick, depending upon the size of a boiler.

ADDITIONAL DIMENSIONS.

A	Diameter, ins.	48	54	60	66	72	78
C	Thickness of inside furnace walls, ins.	17	17	17	17	21½	21½
F	Height of setting wall, ft. and ins.	8–0	8–6	8–8	9–6	9–10	10–6
G	Thickness of bridge wall, ins.	21½	21½	26	26	30½	30½
H	Width of top of bridge wall, ins.	9	9	9	14	14	14
I	Top of bridge wall to shell, ins.	10	12	12	12	12	12
M	Floor line to bottom of shell at front, ins.	55	57	57	59	59	63
O	Distance between tube sheet and rear wall, ins.	22	24	26	26	30	30
*P**	Depth of smoke box, ins.	15	16	16	17	18	20
*Q**	Thickness of front wall, ins.	17	18	18	19	20	22
D†	Overall length of setting walls at floor line, ft. and ins.	$=B+O+P+21$ ins.					
*R**		$=B+O+25$ ins.					
*S**	Thickness of front wall at floor line $=Q+4$ ins.						

* For flush fronts only. † For overhanging fronts.

Return-tubular boilers are usually set with an air-spaced wall, as illustrated in Fig. 179. The air space reduces the temperature of the outer wall surface, but introduces other losses that probably outweigh the gain in economy due to this feature, and it is doubtful if this

form of construction is better than a solid wall. The chief advantage of the air-space construction is that when properly built it tends to prevent the cracking of the outer wall surface and, therefore, makes a better looking setting. One important point in the design of setting walls, to prevent cracking, is the method used to join the ends of the bridgewall with the side walls.

There are two ways of preventing trouble from the expansion of the bridgewall. One is to leave the ends of the bridgewall about an inch away from the side walls, packing the space with asbestos or mineral wool. The elasticity of the packing allows for the expansion of the bridgewall and it prevents the space from becoming clogged with ash and cinders. The other way is to build a recess about 4 inches deep in the side walls having the same shape as a vertical section of the bridgewall and build the ends of the bridgewall into this recess, leaving 1½ inches of clearance at each end for expansion.

The chief function of a bridgewall is to limit the length of the grate surface by presenting a barrier beyond which the spreading of the fuel is prevented; it also aids in mingling the unburned gases and air, so as to cause complete combustion before reaching the tubes. The exact shape or height of the bridgewall does not greatly affect the attainment of these functions. Where girth seams are located in the vicinity of the bridgewall, the top of the wall should be so shaped and of such a distance below the shell that the products of combustion will not impinge directly against the seam. The top of the bridgewall should be built straight across and not follow the contour of the shell as is sometimes done. All the bricks on top of the bridgewall should be laid as headers, so that they may be better able to resist being dislodged by the fire tools.

The side walls of a boiler are generally battered as shown in Fig. 179; and this is good construction; especially for a lug-supported boiler.

The combustion chamber at the rear of the bridgewall tends to aid complete combustion, especially if bituminous coal is used. The rear edge of the bridgewall should be built vertical, and the space behind it down to about the level of the floor should be left open as in Fig. 178, and not filled up and paved as in common practice. The deep combustion chamber at the rear of the bridgewall tends to cause a whirl in the air and gases coming over it and greatly aids in their proper mixture. It also affords storage capacity for the fine ash and cinder that is carried beyond the bridgewall. The practice of filling the space behind the bridgewall to conform to the contour of the shell, as is sometimes done, cannot be too strongly condemned, for it seriously interferes with the accessibility for inspection of the most important surfaces of the boiler, and is certain to prevent complete combustion, if bituminous coal is used. Convenience in cleaning out the combustion chamber is obtained

by arranging the bottom of this chamber as illustrated in Fig. 178; so that the blow-off pipe passes out below the paving, and the cleanout door, which is usually located in the rear wall, is placed on a level with the paving so that no obstacle is offered to raking out the ashes. The blow-off pipe should be placed in a brick trough, the bricks on top being arranged so that they may be readily removed for inspection. This arrangement also admits of the blow-off pipe being placed above the boiler-room floor without interfering with free access to the cleanout doors. The vertical section of the blow-off pipe should be protected from the direct impingement of the flames by slipping a pipe sleeve over it; or a form of protection which is equally as good, with the blow-off pipe accessible for inspection, may be made by laying loose fire-brick in front of the pipe in the form of a V.

The amount of wall surface that is required to be lined with fire-brick is largely a matter of opinion; some engineers prefer to line all of the inner surfaces that are swept by flame and heated gases; but, although this makes a good and lasting setting, it adds considerably to the cost. If the front wall and the side walls over the space indicated by the letters *W, X, Y, Z,* Fig. 178, are lined, together with the bridgewall, and the balance of the setting is laid with good, hard, burned red brick, a satisfactory and durable job will result. Every fifth or sixth course of fire-brick should be a header course to properly bind the lining to the main wall.

Although it has been the general custom to place binder bars on side walls of settings, it is a debatable question as to whether they are of any real benefit or not, except possibly near the front and rear ends of the setting. When a boiler is set with a Dutch oven, there is absolute need of binder bars or their equivalent to carry the thrust of the arch, but no such need exists with the ordinary return-tubular setting where the boiler is hung, and probably not where the boiler is supported by lugs resting on the setting walls.

An important point upon which depends the prevention of cracks in the walls of the setting, is the proper provision for expansion of the boiler. In supporting the boiler on lugs it is generally attempted to secure this feature, in part, by providing rollers under one pair of lugs (usually the rear lugs). These rollers prevent a lengthwise thrust on the walls due to the expansion of the shell; but it is doubtful if they are of much real value because they do not provide for any movement across the setting. For instance, in a 72-in. by 16-ft. boiler the longitudinal distance between the centers of the lugs is about 8 ft., while the distance between centers across the boiler is about 7 ft.; hence, the movement across the setting that should be cared for is about as great as it is lengthwise, and the rollers do not aid the movement in this direction. The method of making allowance for expansion between the shell and setting is shown in Fig. 180, where a 1-inch space is left between them and the space filled with plastic asbestos or asbestos rope. The brick-work should not be allowed to touch the boiler at any point, and special care must

be taken to keep it free from the rear supporting lugs, pockets usually being left in the walls for this purpose. Another point

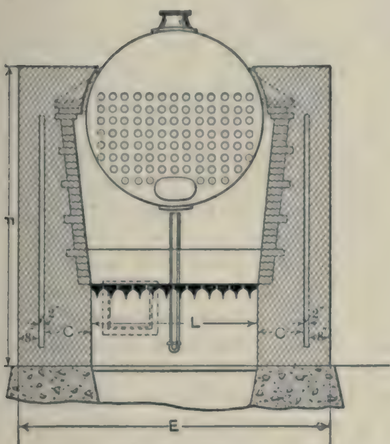

FIG. 179.—CROSS-SECTION OF SETTING.

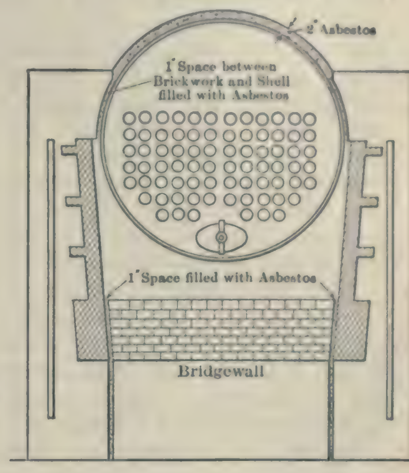

FIG. 180.—SHOWING CLEARANCE AT ENDS OF BRIDGEWALL AND AROUND SHELL.

where clearance is of vital importance is around the pipe connections to the water column and the blow-off pipe, for, unless proper free-

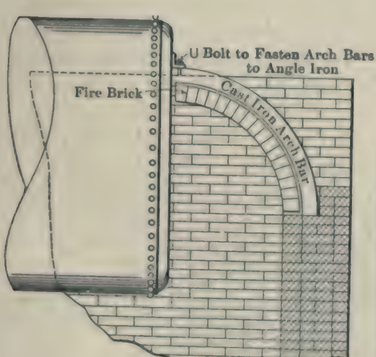

FIG. 181.—BEST FORM OF COVERING FOR REAR CONNECTION.

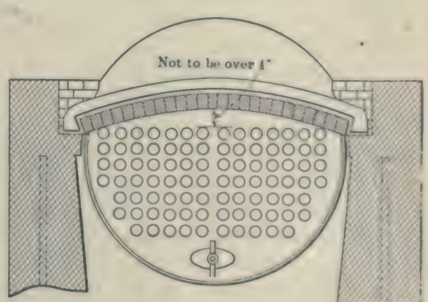

FIG. 182.—CROSS ARCH FOR COVERING BACK CONNECTION.

dom is allowed at these points, there is danger of the pipes being broken off.

The back connection covering is one of the most difficult points about a boiler setting to keep tight. A good plan is shown in Fig. 181.

The usual arrangement of this form of covering is to have an angle iron bolted to the boiler head, with the ends of the arch bars resting on it, but the angle is apt to burn off in a short time. It is better to fasten the tops of the arch bars to the angle iron by U-bolts, as shown in the cut. It is not necessary to bolt the angle iron to the boiler head. With this form of covering the arches follow the movement of the boiler head; and by covering the whole surface with plastic asbestos about 2½ in. thick, a tight job is insured. One of the desirable features of this form of covering for the back connection is that it presents a straight line across the head above the tubes, affording ample protection against overheating to the portion of the head above the water line, without interfering with the free passage of heated gases to any of the tubes.

Another method of closing in the back connection that is commonly used throughout the East, is illustrated in Fig. 182. In setting this type of arch, care must be taken that the head above the water line is not exposed; and it is sometimes necessary to partially block off one or two of the outside tubes to accomplish this. In the arrangement of all types of covering for the back connection the fusible plug must be left uncovered so that it is freely exposed to the products of combustion.

The best covering for the exposed surface on top of a boiler, and the one that will reduce the radiation losses to a minimum, is 85% megnesia from 2 to 3 in. thick, the outer layer being made with a hard finishing cement. The usual covering consists of a layer of bricks laid on edge; but such covering only has cheapness and durability to recommend it, as it is practically worthless as an insulator. The water column should be placed so that the lowest gage cock is at least 3 in. above the tops of the tubes, and the lowest point of vision in the gage glass at least ½ in. above the tops of the tubes.

Fire-brick Furnace Arches. (A. E. Dixon, *Power*, Feb. 20, 1912). —Fire-clay mortar must be very thinly mixed. Within limits, the thinner the better. The brick should be dipped in the mortar in such a way that the surface to be exposed to the flame or heat and two-thirds of the surface in the wall do not receive any mortar. The back of the brick and the rear third of the wall surface only are covered with the mortar. The bricks must be hammered up tight to each other and the seams on the top of the arch should be very thin; the fire-face of all seams must be slightly open, in order to permit the fire-face of the brick to expand slightly when heated.

Fire-clay used for mortar should be the same clay as used in the brick. The best mortar is made from a mixture ranging from 20 to 30% of raw clay and 70 to 80% from old fire-brick ground for this purpose. The two kinds of clay are thoroughly mixed before they are wet, then mixed with water in a tank or tub and allowed to stand at least 48 hours before using.

Fire-brick arches generally have a rise of from 1½ to 2½ in.

per foot of span. The flatter the arch, the greater the thrust upon the skewbacks and buckstays and the greater the pressure on the bricks near the spring of the arch. As fire-brick are not adapted to carry great weights, particularly when exposed to high temperatures, an arch should be given as great a rise as possible, particularly if of any great length of span. Spans under 4 or 5 ft., however, can be made very flat. The thrust of an arch under a uniform load may be computed by the formula:

$$T = \frac{1.5pd^2}{h},$$

in which T = thrust in lbs. per sq. ft. of cross-section per foot of length of arch; p = load on arch, lb. per sq. ft.; d = span of arch in feet, skewback to skewback; h = rise of arch in inches.

In the case of fire-brick arches, the weight per cubic foot can be assumed as 130 lbs.; this will be the load per square foot if the arch is 12 in. thick. The thrust per lineal foot T and the spacing of the buckstays should be such that the tie-rods are not stressed higher than 9000 to 10,000 lbs. per sq. in. Skewback supports are desirable to carry the arch-thrust between the buckstays. Heavy angle or channel irons are frequently employed. These are subjected to bending stresses and should be worked at very low fibre stresses in order to avoid the racking of the brick-work which would be occasioned if they deflected or sprung very much under the loads placed upon them.

To illustrate the effect of the rise of an arch upon the thrust, the thrust of an arch 12 in. thick with a span of 12 ft. 6 in., has been computed for four different rises. This span is approximately the width of the firebox under a 600 H.P. water-tube boiler.

Rise per Foot, Inches.	Thrust, Pounds per Linear Foot.
1.0	2420
1.5	1630
2.0	1220
2.5	975

The total rise for these four cases would be 12.5, 18.75, 25.0 and 31.25 in., respectively, and while the first is so flat that it gives a pressure on the skewbacks of 16.8 lbs. (2420 ÷ 144) per square inch, it is not unreasonably high. The other rises would be too high for a coking arch under the tubes of a water-tube boiler, but they would be all right in a Dutch oven. It is not desirable to run the pressure on fire-brick much over 25 lbs. per square inch or 3600 lbs. per square foot.

Hollow Walls Not an Advantage.—Tests reported in Bulletin 8 of the U. S. Bureau of Mines, 1911, indicate that in furnace construction a solid wall is a better heat insulator than a wall of the same total thickness containing an air space. This is particularly true if the air space is close to the furnace side of the wall, and if

the furnace is operated at high temperatures. If it is desirable in furnace construction to build the walls in two parts, so as to prevent cracks being formed by the expansion of the brick work on the furnace side of the walls, it is preferable to fill the space between the two walls with some "solid" (not firm, but loose) insulating material. Any such materials as ash, crushed brick, or sand offer higher resistance to heat flow through the walls than an air space. Such loose material also reduces air leakage. A 1-in. air space filled with asbestos gave more resistance to the flow of heat than a 2-in. air space with air only.

Fire-brick for Furnaces. (W. N. Best, Proc. N. Y. Railroad Club, 1912.)—With liquid fuel we can attain and maintain a temperature far in excess of that which any ordinary refractory material can withstand. The quality of the various fire-bricks on the market varies greatly. If furnaces are not operated continuously, that is, day and night, it is essential to carefully select fire-brick having no perceptible expansion or contraction, and for welding purposes the furnaces should be constructed of fire-brick capable of withstanding 3000° F., without dripping or melting away. The analysis of such brick is as follows: Silica, 56.15; alumina, 33.29; peroxide iron, 0.59; lime, 0.17; magnesia, 0.121; water and inorganic matter, 9.68; total, 100%.

CHAPTER XIV.

BOILER ATTACHMENTS AND BOILER-ROOM APPLIANCES.

Mud Drums.—When muddy water, such as that of many Western rivers, is used, it is often customary to provide a large mud drum beneath the boiler as shown in Fig. 183. Such drums are often a source of danger on account of external corrosion, which is apt to take place whenever they are in a damp atmosphere at a temperature below the boiling-point of water. The mud drum of the ordinary form of Babcock & Wilcox boiler is shown below the bank of tubes in Fig. 127, page 361. It is made of small diameter, not over 18 in., and for pressures not over 150 lbs. is made of cast iron, which is less liable to corrosion than wrought iron or steel. The mud drum in modern practice is often reduced to a mere pipe, or is dispensed with entirely.

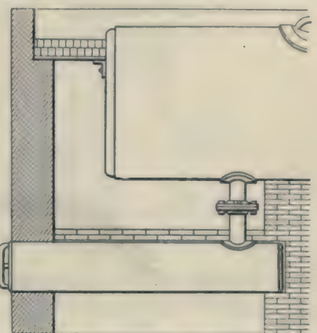

Fig. 183.—Old-style Mud Drum

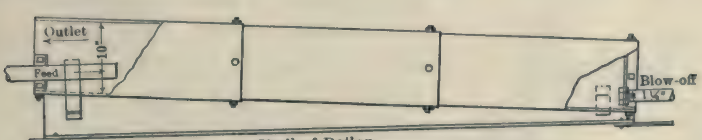

Fig. 184.—Internal Mud Drum.

The mud drum is sometimes put inside of the water and steam drum of a water-tube boiler, as shown in Fig. 184, which represents the mud drum of the Keeler boiler.

The feed water is introduced through the front head into a submerged sheet-steel mud drum. It is heated in its passage through the surrounding water, and before it leaves this drum at the front end is of practically the same temperature as the rest of the water in the boiler. This high temperature causes the precipitation of most of

the impurities in the lower end of the drum to be blown out through the outlet in the rear head provided for that purpose. The internal mud drum also serves to prevent the feed from coming in contact with hot plates, with consequent contraction and leakage at the seams. Impurities carried into the general circulation are discharged through the main blow-off openings in the bottom of the rear header.

Blow-off Pipe.—Two methods of arranging the blow-off pipe of horizontal tubular boilers are shown in Figs. 185 and 186. In the first the descending pipe is protected from the heat of the gases by a sleeve of fire-brick, and the tee and the horizontal pipe are protected by ashes. In the second the blow-off pipe is connected

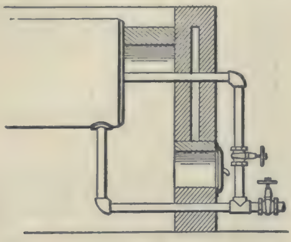

FIG. 185.—BLOW-OFF WITH CIRCULATING PIPE.

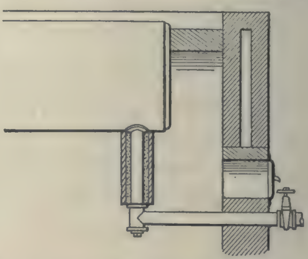

FIG. 186.—BLOW-OFF PROTECTED BY TILE.

to a circulating pipe which enters the rear head of the boiler. Sometimes the descending pipe is protected by a brick pier.

Blow-off Valve.—The common forms of globe or gate valves are scarcely suitable for blow-off valves of boilers, as the seats and valve faces are apt to be abraded and scored by the particles of scale discharged from the boiler. Special valves with renewable discs and seats are commonly furnished by the leading boiler makers.

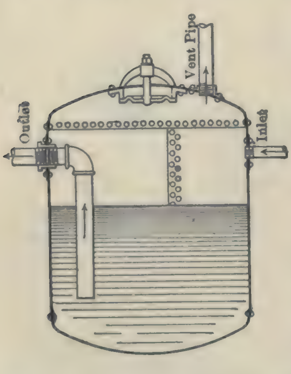

FIG. 187.—BLOW-OFF TANK.

Blow-off Tank.—In buildings in cities, where it is not permitted to blow down a boiler under steam pressure, discharging hot water into the sewer, it is customary to provide a tank, Fig. 187, into which the water is discharged and allowed to cool before being run to the sewer.

Steam Dome.—A braced steam dome, such as was fifty years ago in common use with return-tubular boilers, but is now obsolete, is

shown in Fig. 188. The Massachusetts Board of Boiler Rules says (1910): "The Board does not recommend a steam dome on a boiler, but does recommend the use of a deflecting plate or a dry pipe."

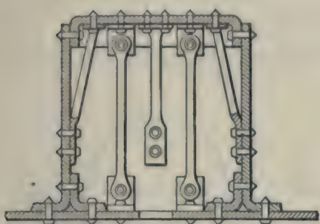

FIG. 188.—BRACING OF A STEAM DOME.

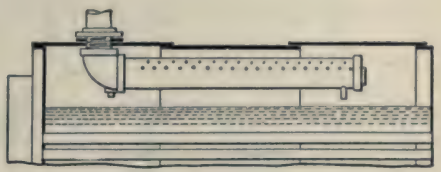

FIG. 189.—DRY PIPE.

Dry Pipe.—One form of dry pipe is shown in Fig. 189. It is a long pipe capped at the end, suspended near the shell in the upper part of the steam space of a horizontal boiler, with its upper portion drilled with a great number of small holes whose aggregate area is about double the cross-sectional area of the pipe. With such a pipe the amount of water discharged with the steam from the boiler rarely exceeds 0.5% unless the water level is carried too high or the water is of such a character as to cause foaming.

Connecting Steam Pipes to Boilers.—Fig. 190 (from *The Locomotive*, 1890) shows an incorrect method of attaching pipes connecting a pair of boilers to an overhead steam main. The cast-iron pipe *C*

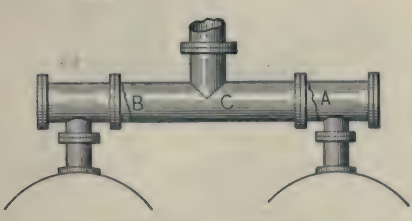

FIG. 190.—INCORRECT PIPING.

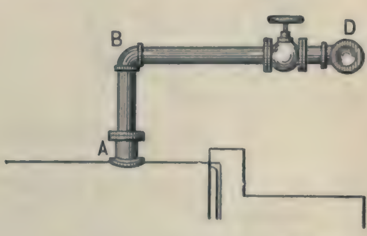

FIG. 191.—IMPROVED PIPING.

formed a rigid connection between the two boilers, allowing no provision for expansion and contraction. After the boilers had been a short time in service the tee at *A* cracked as shown; it was replaced and soon afterward the pipe *C* cracked at *B*. In another case, observed by the author, in which two water-tube boilers were connected in a

similar manner, but with a wrought-iron pipe, the expansion and contraction brought a strain on the boilers themselves, causing one of them to leak seriously at a riveted seam.

Fig. 191 shows a common method of connecting a boiler to a steam main. The vertical pipe AB is connected by a long horizontal pipe to the main D, which gives the piping system the required flexibility.

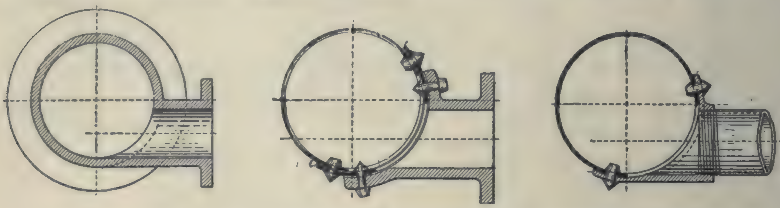

FIG. 192.—ECCENTRIC FITTINGS FOR BRANCHES.

In modern plants with high pressures the elbow D is usually replaced by a long bend of wrought-iron or steel pipe ,and cast-iron flanges and elbows are generally avoided.

Eccentric Fittings.—When several boilers in a battery discharge into a horizontal steam main or drum from which pipes lead to the engine it is essential that connections be so made that at no time is it possible for any water to collect in the lower part of the drum. The best way to insure this is to have the connections to the drum made of eccentric fittings, so that the bottom of the inside of the fitting, or

FIG. 193.—ECCENTRIC FITTINGS FOR PIPE LINES.

nozzle, is at the level of the bottom of the drum. Three forms of such nozzles are shown herewith, Fig. 192.

Fig. 193 shows eccentric fittings for a long line of steam pipe, when the size of the main is to be reduced, which allow water of condensation to flow freely onward.—(*The Locomotive,* 1900.)

Fire-Doors.—The ordinary form of fire-door is shown in Fig. 194. The admission of air through the adjustable opening in front and thence through the perforated plates tends to keep the door from overheating and warping. Fig. 195 shows a form of balanced door.

The door is suspended by horizontal pivots at its upper edge, and a heavy counterbalance weight is mounted above it in such a position

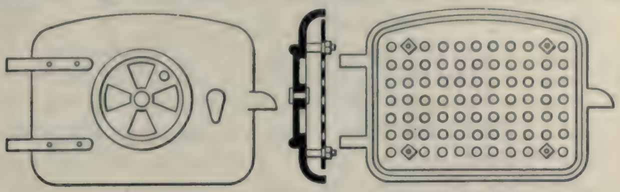

FIG. 194.—DETAILS OF FIRE-DOORS.

that if the door when closed is given a slight push it will open inwards and will close again when a push is given the counterweight. Doors of this type are frequently used on ocean steamers.

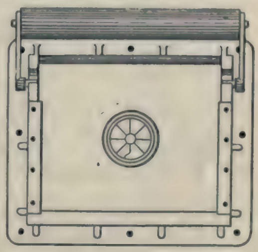

FIG. 195.—BALANCED FIRE-DOOR.

Fire-door Openings.—With externally-fired boilers the fire-door opening is part of the brick setting of the furnace. The opening is arched over with arch fire-brick or with a special tile of the proper shape and material. The door opening is from 12x16 in. to 16x20 in. For wide grates two small doors are commonly preferred to one large one, and three or more doors if the grate surface is over 8 ft. in width. With internally-fired boilers the fire-door opening is part of the boiler structure. Fig. 196 shows different methods of making such openings in vertical tubular or other internally-fired boilers.

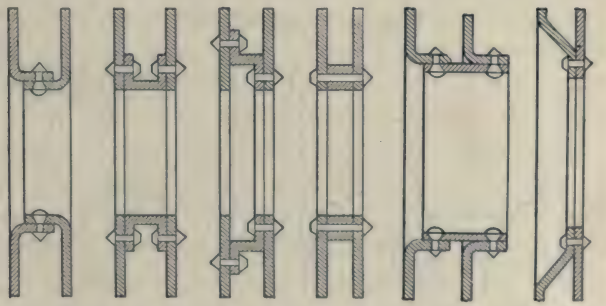

FIG. 196.—FIRE-DOOR OPENINGS FOR INTERNALLY-FIRED BOILERS.

Red-hot Fire-doors.—A complaint was made that the fire-doors of a certain water-tube boiler were frequently red hot and it was feared

they would soon be burned out. The furnace was roofed over by an inclined brick arch which sometimes became intensely hot and radiated heat onto the fire-doors and into the fireman's face whenever he opened a door. The coal was Pittsburgh bituminous. It was discovered that the doors never got visibly red unless the fireman waited at least 15 minutes after firing, and that when they did get hot the firing of a single shovelful of coal just beyond the dead plate between the door and the grate bars cooled the door so that it would not again become red hot for at least ten minutes. When the fireman changed his method of firing, and fired in smaller quantities at more frequent intervals, there was no more complaint of hot fire-doors.

Nozzles for Attaching Pipes to Boilers.—For pressures not exceeding 150 lbs. it is customary to make nozzles of cast iron, but for higher pressures forged steel is recommended. Fig. 197 shows a forged steel nozzle for a steam pipe connection containing an internal pipe which connects with a dry-pipe inside of the boiler.

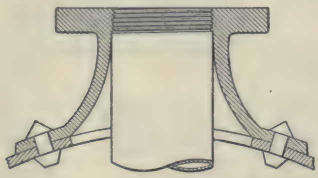

FIG. 197.—FORGED STEEL NOZZLE WITH DRY-PIPE CONNECTION.

Brackets and Hangers for Supporting Boilers.—Horizontal tubular boilers of moderate sizes are usually supported on the brick walls of the setting by means of cast-iron brackets riveted to the shell, Fig. 198, two such brackets being used on each side, and the rear ones often resting on

FIG. 198.—SIDE BRACKETS.

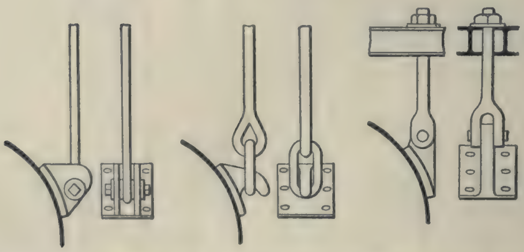

FIG. 199.—METHODS OF SUPPORTING BOILERS FROM ABOVE.

rollers carried by a plate on the top of the wall, so as to allow of expansion and contraction. Large high-pressure boilers and also

water-tube boilers are generally carried by hangers from overhead supports which are entirely free from the brickwork setting. Fig. 199 shows different forms of hangers. The brackets for these hangers are made of cast or forged steel.

Feeding Boilers.—The old practice of feeding boilers through the mud drum is now generally condemned. It tends to cause corrosion and pitting of the metal near the inlet orifice, and it stirs up the mud in the drum, carrying it up into the boiler where it may cause the formation of scale. Feeding through the front head of a tubular boiler below all the tubes is also condemned on account of the frequent changes of temperature caused thereby. The following method of feeding return-tubular boilers is recommended by the Hartford Steam Boiler Inspection and Insurance Co. The feed-pipe enters the boiler through the front head just above the top row of tubes, and about three inches from the shell. It then extends back to within a foot of the back head and crosses over to the other side of the boiler. It then passes down between the tubes and the boiler shell and discharges below the lowest row of tubes towards the axis of the boiler. The vertical pipe in front of the boiler contains a stop valve, a check valve and a union. The advantage of this method lies in the fact that before the feed-water discharges itself it has become as hot as the water into which it is discharged, and consequently there is no chilling effect produced, and no unequal expansion and contraction of the boiler. Brass pipe, inside of the boiler, is preferable to iron pipe, because it will not choke with scale as quickly as iron pipe. The piping can be so connected together that only the portion running across the boiler need be taken out for cleaning, while the long section may be cleaned in place by running an iron rod through it.

The feed pipe of water-tube boilers with horizontal drums is usually made to enter the front head and to travel to a point near the rear head where the water is discharged into the rapidly flowing rearward current in the boiler. This method is generally satisfactory except when the water contains a great deal of carbonate of lime and magnesia, which is apt to be deposited as scale in the downcome pipes at the rear of the boiler. In such case it is better to provide the boiler with an internal mud drum and feed into it. (See Fig. 184.)

Attachments to Boilers. (Massachusetts Boiler Rules.) *Safety Valves.*—Each safety valve shall have full-sized direct connection to the boiler. No valve shall be placed between the safety valve and the boiler, nor on the escape pipe between the safety valve and the

atmosphere. Safety valves shall not exceed 5 in. diameter, and shall be of the direct spring-loaded type, with seat and bearing surface of the disc at an angle of about 45° to the center line of the spindle, with a lifting device so that the disc can be lifted from its seat not less than ⅛ the diameter of the valve when the pressure on the boiler is 75% of that at which the safety valve is set to blow.

Steam Gage.—Each boiler shall have a steam gage connected to the steam space of the boiler by a siphon, or equivalent device, in such manner that the gage cannot be shut off from the boiler except by a cock with T or lever handle, which shall be placed on the pipe near the steam gage.

Steam Gage Dial.—The dial of the steam gage shall be graduated to not less than $1\frac{1}{2}$ times the maximum pressure allowed on the boiler.

Attaching Test Gage.—Each boiler shall be provided with a ¼-in. pipe for attaching inspector's test gage when the boiler is in service, so that the accuracy of the boiler steam gage can be ascertained.

Water Glass.—Each boiler shall have at least one water glass, the lowest visible part of which shall be above the fusible plug and lowest safe water line.

Gage Cocks.—Each boiler shall have three or more gage cocks, located within the range of the visible length of water glass, when the maximum pressure allowed exceeds 25 lbs. per sq. in., except when such boiler has two water glasses, located not less than 3 ft. apart, on the same horizontal line.

Feed Pipe.—Each boiler shall have a feed pipe fitted with a check valve, and also a stop valve or stop cock between the check valve and the boiler, the feed water to discharge below the lowest safe water line. Means must be provided for feeding a boiler with water against the maximum pressure allowed.

Stop Valve.—Each steam outlet from a boiler (except safety valve connections) shall be fitted with a stop valve.

When a stop valve is so located that water can accumulate, ample drains shall be provided.

Damper Regulator.—When a damper regulator is used, the boiler pressure pipe shall be fitted with a valve or cock, and shall be connected to the steam space of the boiler.

Fusible Plugs to be filled with pure tin; plugs to project through the sheet not less than 1 in. In horizontal return boilers, the plugs are to be located in the rear head, not less than 2 inches above the upper row of tubes; in water-tube boilers with horizontal drums, Babcock & Wilcox type, not less than 6 inches above the bottom of the drum, over the first pass of the products of combustion; in new designs, at the lowest permissible water level, in the direct path of the products of combustion, as near the primary combustion chamber as possible.

The Board of Boiler Rules Recommends: The installation of more than one safety valve on a boiler permitted to carry over 25 lbs. pressure per sq. in.

Elliptical handholes of the following sizes: $2\frac{1}{4} \times 3\frac{1}{4}$ in.; $2\frac{5}{8} \times 3\frac{3}{4}$ in.; $3 \times 4\frac{1}{2}$ in.; $3\frac{1}{2} \times 5$ in.; 4×6 in.

Discontinuing from service, and not repairing a boiler on which a longitudinal lap crack is discovered.

The Board Does not Recommend: The use of cast-iron or copper steam pipe.

Attaching diagonal stays to shell plates directly over the fire.

Safety-Valves.—The Massachusetts rule for area of safety-valves is $A = \frac{W \times 70}{P} \times 11$, in which A = area in square inches per square foot of grate surface, W = pounds of water evaporated per second per

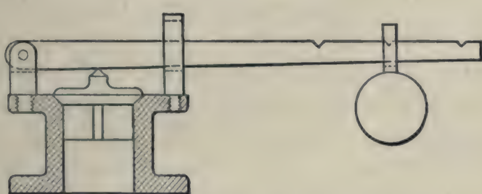

FIG. 200.—LEVER SAFETY-VALVE.

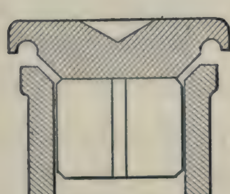

FIG. 201.—BEVEL-SEAT SAFETY-VALVE.

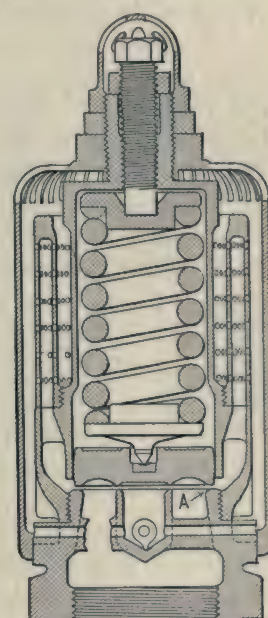

FIG. 202.—CROSBY FLAT-SEAT SAFETY-VALVE.

square foot of grate surface = P = absolute pressure of the steam in pounds per square inch. The words "per square foot of grate surface" seem to be a concession to an old custom of proportioning the area of a safety-valve to the grate surface, but in this formula they are mere surplusage, for the formula is equivalent to $A = 770\ W/P$, in which A is square inches of valve area and W pounds of water evaporated per second. It is also equivalent to Napier's formula for flow of steam through an orifice, $W = AP/70$, assuming the area of opening

of the valve = 1/11 of the disc area. This rule will probably soon be obsolete.

Fig. 200 shows the old style of safety-valve, in which an ordinary bevel-seated valve is held to its seat by a weighted lever. Its chief defect was that it opened only slightly when the steam pressure reached the limit for which the weight on the lever was set, and would not lift higher as the pressure increased. For high-pressure boilers the "pop" safety-valve is in almost universal use. The valve is held down by a compressed coiled spring, and is so shaped that after it opens the steam presses upon a larger area than that which is exposed to pressure when the valve is shut. This causes the valve to lift higher than the old-style valve, and retards its closing until the steam pressure has been reduced to a point slightly below that at which the valve opens. Fig. 201 shows such a valve, called a single or bevel-seated valve, and Fig. 202, another, called a double-seated annular valve, in which the additional area, upon which the steam presses when the valve is opened, is located at the center of the valve disc. Both the inner and outer seats of this valve are flat. Fig. 202 also shows the coiled spring, which is adjusted to the allowed pressure by the screw and lock-nut shown above. The casing of the valve may be provided with a muffling device, for lessening the noise when steam is blowing off. The rounded edge shown at A increases the discharge about 12 per cent above that of a sharp-edged outlet.

The boiler rules of the State of Massachusetts provide:

"No valve of any description shall be placed between the safety valve and the boiler, or on the escape pipe between the safety-valve and the atmosphere."

Discharging Capacity of Safety-Valves.—The table on page 471 shows the discharge of Crosby safety-valves for the various lifts given:

Safety-valve Rules of the A. S. M. E. Boiler Code.—In 1914 the Committee had several conferences with the principal safety-valve manufacturers of the country and an agreement was finally reached on the rules given in condensed form below. The discharging capacity of a valve is based on Napier's rule with a coefficient of discharge of 0.96, the formula being $W = 3600 \times 3.1416 \times DL \times 0.96 \times 0.707 \times P/70$, or $W = 109.66\, DLP$ pounds per hour for a 45° bevel seat valve. For flat seat valves the factor 0.707 is omitted and the formula becomes $W = 155.11\ DLP$ pounds per hour. The table on page 472 is calculated from the first formula. (D = diam. L = lift, both in inches, P = absolute pressure, lbs. per sq. in., G = gage pressure + 14.7.)

ASSUMED LIFTS, VARYING WITH VALVE SIZE AND PRESSURE.

Valve Diam.	Pressures (Lbs. per Sq. In.)									
	Gauge 25 Abs. 39.7	Gauge 50 Abs. 64.7	Gauge 75 Abs. 89.7	Gauge 100 Abs. 114.7	Gauge 125 Abs. 139.7	Gauge 150 Abs. 164.7	Gauge 175 Abs. 189.7	Gauge 200 Abs. 214.7	Gauge 225 Abs. 239.7	Gauge 250 Abs. 264.7
2	.079	.071	.064	.059	.057	.054	.051	.047	.044	.042
2½	.098	.088	.080	.074	.071	.068	.063	.059	.055	.052
3	.118	.106	.096	.088	.085	.082	.076	.071	.066	.062
3½	.138	.124	.113	.103	.099	.095	.088	.083	.077	.073
4	.157	.141	.129	.118	.113	.109	.101	.094	.088	.083
4½	.177	.159	.145	.133	.127	.122	.114	.106	.099	.094

LBS. OF STEAM DISCHARGED PER HOUR, BY BEVEL-SEATED VALVES AT LIFTS GIVEN ABOVE

2	730	1067	1,332	1,568	1,844	2,058	2,237	2,231	2,435	2,565
2½	1132	1654	2,081	2,459	2,871	3,240	3,455	3,658	3,804	3,970
3	1636	2390	2,997	3,508	4,125	4,698	5,001	5,283	5,478	5,679
3½	2232	3263	4,116	4,790	5,605	6,337	6,756	7,205	7,457	7,802
4	2902	4240	5,370	6,272	7,311	8,310	8,860	9,325	9,739	10,136
4½	3681	5379	6,790	7,953	9,244	10,463	11,252	11,830	12,326	12,918

LBS. OF STEAM DISCHARGED PER HOUR, BY FLAT-SEATED VALVES, AT LIFTS GIVEN ABOVE

2	1115	1633	2,040	2,406	2,830	3,161	3,438	3,586	3,749	3,952
2½	1729	2530	3,188	3,771	4,407	4,976	5,310	5,628	5,858	6,115
3	2498	3657	4,591	5,382	6,331	7,201	7,687	8,128	8,434	8,749
3½	3408	4991	6,305	7,349	8,604	9,733	10,384	11,086	11,482	12,020
4	4431	6485	8,226	9,622	11,222	12,762	13,620	14,346	14,995	15,618
4½	5620	8228	10,402	12,200	14,189	16,070	17,295	18,201	18,979	19,900

The formulæ for discharge, used in computing the table are for flat-seated valves, $W=1.10\pi Dl\times\frac{P}{70}\times 3600$; for bevel-seated valves, $W=(2.22Dl+1.11l^2)\times\frac{P}{70}\times 3600$; W = lbs. steam per hour; D = diam. of valve, ins.; l = lift, ins.; P = absolute pressure, lbs. per sq.in.

The discharge capacity of a flat seat valve is 1.41 times that of a 45° bevel seat valve of the same diameter and lift.

Safety Valve Requirements. Each boiler shall have two or more safety valves, except a boiler for which one safety valve 3-in. size or smaller is required by these Rules.

The safety valve capacity for each boiler shall be such that the safety valve or valves will discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6%

CAPACITIES OF SAFETY VALVES

Discharge Capacities of Direct Spring-loaded Pop Safety Valves with 45° Bevel Seats. Pounds per Hour.

Gage Pres. Lbs. per Sq.in.	Diam. / Lift, in.	1 in. Min. 0.02	1 in. Int. 0.04	1 in. Max. 0.05	1½ in. Min. 0.03	1½ in. Int. 0.05	1½ in. Max. 0.06	2 in. Min. 0.04	2 in. Int. 0.06	2 in. Max. 0.07	2½ in. Min. 0.04	2½ in. Int. 0.06	2½ in. Max. 0.08
15	...	65	131	163	146	245	293	261	391	456	326	488	651
25	....	87	174	218	196	326	392	349	523	610	435	653	871
50	....	142	284	354	320	532	639	568	851	994	710	1064	1419
75	....	197	393	492	443	738	886	787	1181	1377	984	1475	1968
100	....	252	503	629	566	944	1133	1007	1510	1761	1258	1887	2516
125	....	307	613	767	689	1149	1379	1224	1836	2145	1532	2299	3064
150	....	362	723	904	813	1355	1625	1438	2158	2529	1806	2710	3613
175	....	416	833	1040	936	1561	1872	1664	2497	2913	2081	3121	4161
200	....	471	941	1178	1060	1766	2119	1884	2826	3296	2354	3532	4709
225	....	526	1052	1315	1183	1972	2366	2104	3154	3680	2629	3944	5258
250	....	581	1161	1451	1307	2177	2613	2322	3484	4064	2903	4355	5807
275	....	635	1271	1589	1430	2383	2860	2542	3813	4448	3177	4766	6355
300	....	698	1397	1746	1553	2589	3107	2762	4143	4832	3452	5177	6903

Gage Press. Lbs. per Sq.in.	Diam. 3 in. Lift. Min. 0.05	Diam. 3 in. Int. 0.08	Diam. 3 in. Max. 0.10	Diam. 3½ ins. Min. 0.06	Diam. 3½ ins. Int. 0.09	Diam. 3½ ins. Max. 0.11	Diam. 4 ins. Min. 0.07	Diam. 4 ins. Int. 0.10	Diam. 4 ins. Max. 0.12	Diam. 4½ ins. Min. 0.08	Diam. 4½ ins. Int. 0.11	Diam. 4½ ins. Max. 0.13
15	489	782	977	684	1,026	1,254	912	1,303	1,564	1,173	1,613	1,906
25	653	1046	1,307	914	1,372	1,676	1219	1,742	2,090	1,568	2,156	2,547
50	1064	1703	2,129	1490	2,235	2,732	1987	2,839	3,406	2,555	3,513	4,151
75	1475	2361	2,951	2066	3,099	3,788	2754	3,935	4,722	3,542	4,870	5,756
100	1887	3019	3,774	2642	3,963	4,843	3522	5,032	6,038	4,529	6,227	7,358
125	2299	3677	4,596	3218	4,826	5,899	4290	6,128	7,354	5,516	7,583	8,963
150	2710	4335	5,419	3794	5,690	6,954	5058	7,226	8,670	6,503	8,940	10,566
175	3121	4993	6,242	4369	6,553	8,010	5824	8,320	9,984	7,490	10,298	12,173
200	3532	5651	7,064	4946	7,418	9,068	6593	9,420	11,305	8,475	11,655	13,773
225	3944	6310	7,890	5521	8,280	10,120	7361	10,514	12,616	9,465	13.013	15,383
250	4355	6968	8,708	6097	9,143	11,175	8130	11,614	13,938	10,448	14,366	16,980
275	4766	7620	9,533	6672	10.005	12,333	8895	12,707	15,248	11,438	15,728	18,585
300	5177	8280	10,358	7248	10,875	13,290	9668	13,807	16,568	12,428	17,088	20,195

Valves 1¼ in. diam. with lifts 0.03, 0.04 and 0.05 in. give a discharge for 0.04 in. lift the same as that of a 1-in. valve with 0.05 in. lift; with 0.03 in. lift 25% less and with 0.05 in. lift 25% greater.

above the maximum allowable working pressure, or more than 6% above the highest pressure to which any valve is set.

One or more safety valves on every boiler shall be set at or below the maximum allowable working pressure. The remaining valves may be set within a range of 3% above the maximum allowable working pressure, but the range of setting of all of the valves on a boiler shall not exceed 10% of the highest pressure to which any valve is set.

Safety valves shall be of the direct spring-loaded pop type. The vertical lift of the valve disc may be made any amount desired up to a maximum of 0.15 in. The diameter measured at the inner edge of the valve seat shall be not less than 1 in. or more than 4½ in.

Each safety valve shall have plainly stamped or cast on the body: (*a*) The name or trade-mark of the manufacturer, (*b*) The nominal diameter with the words "Bevel Seat" or "Flat Seat," (*c*) The steam pressure at which it is set to blow, (*d*) The lift of the valve disc from its seat, measured immediately after the sudden lift due to the pop, (*e*) The weight of steam discharged in pounds per hour at the pressure for which it is set to blow.

The minimum capacity of a safety valve or valves to be placed on a boiler shall be determined on the basis of 6 lbs. of steam per hour per sq. ft. of boiler heating surface for water tube boilers, and 5 lbs. for all other types of power boilers, and upon the relieving capacity marked on the valves by the manufacturer, provided such marked capacity does not exceed that given in the table, in which case the minimum safety valve capacity shall be determined on the basis of the maximum relieving capacity given in the table for the particular size of valve and working pressure for which it was constructed. The heating surface shall be computed for that side of the boiler surface exposed to the products of combustion, exclusive of the superheating surface.

Safety Valves for Locomotives.—A committee of the American Railway Master Mechanics' Association presented a report on safety valves in 1912, giving the following formula for 45° bevel seat valves. $DLP = 0.036H$, in which $D =$ total of the diameters of the inner edge of the seats of the valves required; $L =$ vertical lift in inches; $P =$ absolute pressure lbs. per sq. in.; $H =$ total heating surface of boiler sq. ft. (superheating surface not included). Every locomotive should be equipped with not less than two and not more than three safety valves, the size to be determined by the formula. The valves are to be set as follows: The first at boiler pressure, second 2 lbs. in excess, third 3 lbs. in excess of second. Manufacturers should be required to stamp on the valve the lift in inches as determined by actual test.

The formula corresponds to the discharge calculated by Napier's rule with a coefficient of flow of 0.973 and an evaporation of 4 lbs. per square foot of heating surface per hour. It is evident that safety valves proportioned according to this formula will have a relieving capacity much less than the evaporative capacity of a locomotive boiler with large fire-boxes and short flues. The Consolidated Safety Valve Co. suggests the formula $DLP = C_1H_1 + C_2H_2$ in which H_1 is fire-box and H_2 flue heating surface, sq. ft., and C_1 and C_2 are

constants to be determined by experiment, C_1 being considerably larger than C_2

Damper Regulators.—For the purpose of automatically varying the force of draft with the demand for steam, damper regulators are in common use. They are operated by the steam pressure, and when this rises above a desired point they close, more or less, the flue damper, and open it when the pressure falls. There are many different varieties in the market. One form is shown in Fig. 203. It consists of a brass cylinder in which is a piston connected to a spring, which balances the steam pressure. Condensed steam from the boiler is admitted under the piston. The spring is in a separate chamber, so that no steam or water can come in contact with it. Steam is admitted

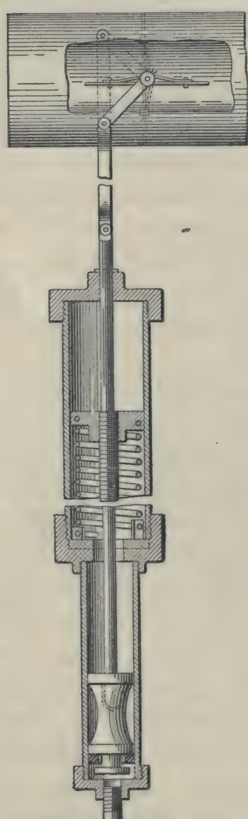

FIG. 203.—DAMPER REGULATOR.

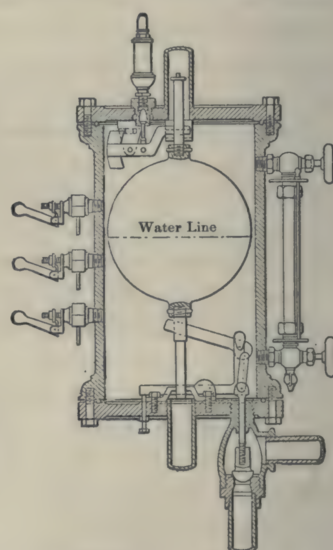

FIG. 204.—FEED-WATER REGULATOR AND ALARM COLUMN.

to the pipe, at the bottom, and any variation in pressure results in a movement of the piston and rod so that the damper is opened or closed in proportion to the change in pressure. Connection is made direct, when possible, but if not, a rocker shaft made of piping may be used to transmit the motion.

Feed-water Regulator.—A combined feed-water regulator and alarm-water column is shown in Fig. 204. Control of the feed-water supply is effected by a valve placed at the bottom, which controls the action of the pump by means of a back pressure regulator, which is placed in the steam pipe of the pump and regulates the pressure in the water main from the pump to the boiler. By this arrangement the pump cannot cause an excessive pressure in the water main if the boiler should take but little water for a period of time. The valve at the bottom of the regulator is connected by means of levers to a cast bronze float made in one piece and copper plated, so that it cannot collapse or become waterlogged. This float opens and closes the valve according to the requirements of the boiler, so that the water level is maintained at a nearly constant height and cannot fall more than two inches below that desired without sounding the alarm. Gauge cocks and a gauge glass are placed on the drum of the regulator. The apparatus should be blown out frequently to make sure that it is clear of obstructions. Where it is used in connection with a battery of boilers, one of the water columns is used on each boiler.

The Copes Feed-water Regulator.—Fig. 205 represents diagrammatically the Copes submerged tube regulator. It consists essentially

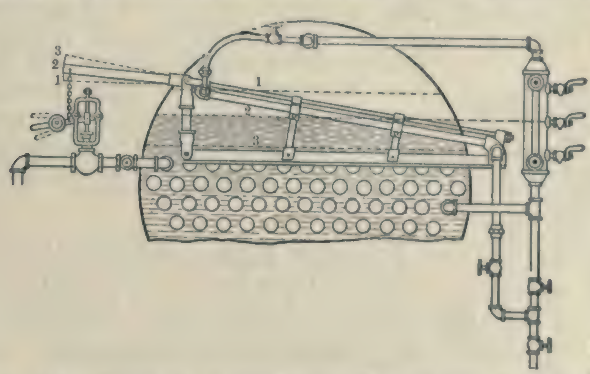

FIG. 205.—DIAGRAM OF THE COPES FEED-WATER REGULATOR.

of an inclined thermostatic tube which controls the opening of a balanced valve in the feed-pipe. The maximum and minimum heights at which it is deemed safe to carry the water levels are first decided upon and then the thermostat is installed with sufficient slope so that when the water level is at its minimum height, there is no water in the expansion tube, and when the level is at the maximum height, the tube is filled with water. The level in the tube fluctuates with the level in the boiler.

The operation of the regulator is as follows: Suppose the level is at the middle gauge (No. 2 in Fig. 205) and the boiler load is 100%. The expansion tube is half submerged, and has a length corresponding. When an increased load comes on, with a slight drop in steam pressure, accompanied by a more rapid liberation of steam, a rise takes place in the boiler water level. This raises the level of the water in the expansion tube slightly, decreases its temperature, causing the tube thereby to shorten and the valve to shut, decreasing the rate of feed to the boiler. This is desired in order to obtain the maximum capacity of the boiler, since the heat being generated in the furnace is used to generate steam and not to heat feed water at a time when every pound of steam counts. As the heavy load continues, the evaporation of water causes the level to drop and this causes expansion of the thermostat and gradual opening of the feed valve. The level in the boiler drops and the feed valve opens until a point is reached where the rate of feed equals the rate of evaporation and equilibrium is restored, the water being at a new level.

A decrease in load means a smaller steam demand, and a rise in boiler pressure, and the water level falls slightly, with a heating up and expansion of the thermostat. This causes the feed valve to open wider and feed the water at a greater rate to the boiler, thus absorbing and storing heat. A decreasing load is then accompanied by a rising water level. This cools the expansion tube and slowly cuts down the feed again, so that at any fixed load position the rate of feed finally becomes just equal to the rate of evaporation, and equilibrium is again secured, the water level now standing in the boiler at a somewhat greater height than it did at the normal load. Every load on the boiler has some corresponding proper water level which the regulator maintains.

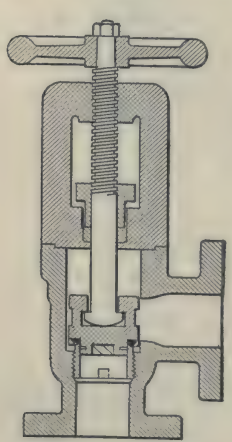

FIG. 206.—BLOW-OFF VALVE.

Blow-off Valve.—The blow-off valve at the bottom of a boiler or of a mud-drum is subjected to severe service on account of its discharging particles of scale and mud which cause wear of the seat. When the valve is screwed down particles of scale are apt to be caught between the valve and the seat, damaging them and causing leaks. For this reason blow-off valves are usually constructed with removable disks and seats. Fig. 206 shows a form of blow-off valve. The valve plug or piston may be lifted by the screw stem so as to give a full opening for the escape

of scale and other impurities. The valve or disk seats on a ring fitted into the casing and the disk and ring may readily be removed for repairs or renewal.

Surface Blow-off.—Many scale-forming materials when precipitated from solution or formed by evaporation float at first as scum on the surface of the water in the boiler, from which they may be removed directly by means of a surface blow-off. This consists of a funnel with a rectangular mouthpiece extending across the width of the boiler at the water line, so placed as to receive the surface current of water, connected by a pipe to a valve outside the boiler, through which the scum collected in the funnel may be discharged. Automatic skimming devices are sometimes used, which keep up a circulation of water from the skimming funnel through a settling chamber or a filter, from which the water is returned to the boiler. The Hotchkiss "boiler cleaner," one of this type, is shown in Fig. 207. The settling-chamber is placed above the boiler. When the valves H and H are opened, steam rises through both pipes (the valve F at first being open to allow escape of air) until it fills the chamber B. This steam condenses, and, because of the partial vacuum thus formed, water rises and finally fills the chamber. Then the circulation begins, the dirt-laden water rising along the pipe D, and, after passing through the chamber B, where much of this sediment drops to the bottom, continues its course back into the boiler through the pipe E. The valve F is occasionally opened, which discharges the dirt from the bottom of the chamber B.

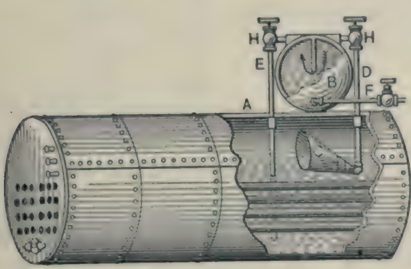

FIG. 207.—CONTINUOUS SURFACE BLOW-OFF.

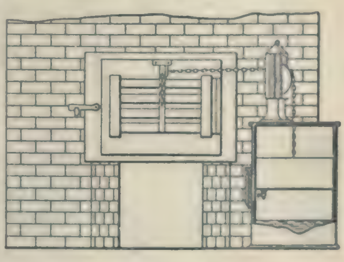
FIG. 208.—DEVICE FOR ADMITTING AIR.

Regulating the Air Supply over the Fire.—Fig. 208 shows a device patented by Cliff in 1855 for admitting air through a furnace door immediately after firing and gradually shutting it off as the smoky

gases distilled from the coal decreased. As the door was opened the hollow piston in the adjoining cylinder dropped into the water in the bottom of the cylinder, which water ran through an upward opening valve into the piston.

As the door was closed after firing the attached chain caused the piston to rise, carrying its load of water with it, the valve being closed. The weight of the water and piston caused the shutter to move up and open wide, and as the water ran out of the piston the weight of the slide (and a counter weight) caused the slide to move down slowly, thus gradually closing the openings until, when the piston was empty, the secondary air supply was entirely cut off.

Many similar devices have been used in recent times, using air instead of water in the cylinder. In these the opening of the door raised a weighted piston and opened the slides in the door, and after the door was closed the air beneath the piston leaked around it into the chamber above while the piston gradually descended and closed the slides.

The ordinary pneumatic or compressed-air "door-check" has been successfully used for this purpose. It may be arranged to slowly close either the door itself or an air valve in the door. It acts by preventing the door from being entirely closed immediately after firing, until air, which has been compressed in the device by the opening of the door, leaks out of it.

Water-tube Cleaner.—Fig. 209 shows a tool used for removing scale from the tubes of a water-tube boiler. It consists of a small water turbine, using water supplied at about 100 pounds per square inch through a hose from a pump, rotating at high speed a shaft and a series of arms carrying hardened steel cutters. The tool is pushed back and forth through the tubes and the water from the turbine washes away the deposit that has been loosened by the cutters.

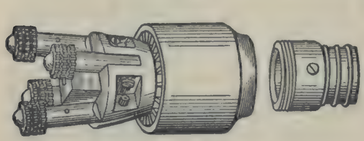

FIG. 209.—TURBINE WATER-TUBE CLEANER.

Steam Separators.—There are many different forms of separators in the market, one of which is shown in Fig. 210. Steam enters at the top and passes around the sides of the inclined baffles, which catch the "entrained" water and divert it to the chamber below, whence it is removed by a trap.

Another form of steam separator is shown in Fig. 210*a*. The steam is given a whirling motion by the helical baffle in the pipe, forcing the drops of water to the circumference, where it escapes at the edge of the opening leading to the water chamber beneath.

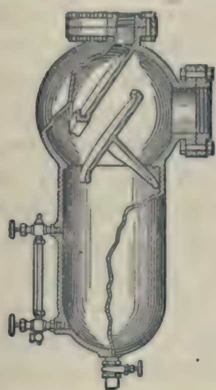

Fig. 210.—Steam Separator.

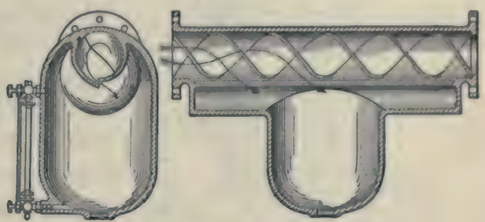

Fig. 210*a*.—Steam Separator.

High- and Low-water Alarm.—Fig. 211 shows a common form of water column, provided with a high- and low-water alarm. The float, usually made of copper, operates a steam whistle whenever the water gets too high or too low. The three threaded holes on each side are for the attachment of gauge cocks on either side of the column, those on the other side being plugged.

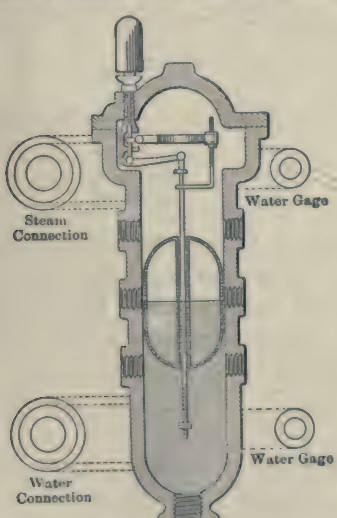

Fig. 211.—Safety Water Column.

Gauge Glass and Gauge Cocks.—Every boiler should be provided both with a gauge glass to indicate the height of the water level, and three gauge cocks, the middle one set at the desired water level and the other two at the highest and lowest allowed levels. These should be opened frequently as a check on the indications of the gauge glass, which on account of clogging of the connections may indicate a false level. They are usually connected to a water column, as in Fig. 212. For water-tube boilers the valves of the gauge cocks are usually closed by weights, which are lifted by long rods easily reached by the fireman.

Steam Gauges.—The Bourdon spring steam gauge is in universal use for steam boilers. It depends on the principle that a bent tube subjected to internal pressure tends to straighten out. The tube is usually made of brass, somewhat flattened, closed at one end, and bent into a C-shape. The open end is connected to a pipe leading from the boiler, and the movement of the closed end is multiplied by a pinion and sector mechanism, so as to move an index on a dial. The dial is calibrated by comparing its indications with those of a mercury column. The piping leading to the gauge should be as short and direct as possible. No valves or stop cocks are used other than the cock at the gauge. Piping should be no smaller than the fitting on the gauge and should be so arranged that there will be a water pocket next the gauge, thus preventing the steam from coming in contact with the bent tube and, by its heat, so altering the temper of the tube as to make the reading inaccurate. Methods of doing this are shown in Fig. 213.

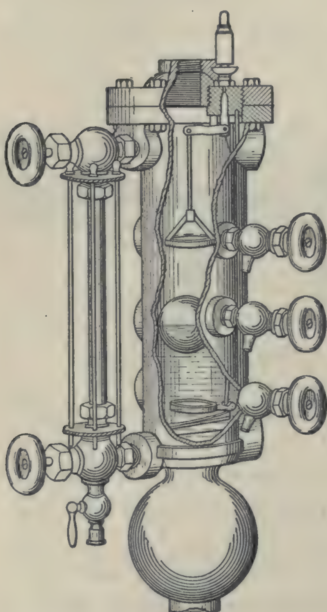

Fig. 212.—Water Column, Gauge Glass and Gauge Cocks.

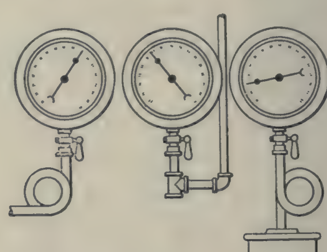

Fig. 213.—Steam Gauge Connections.

The Venturi Meter.—When water flows through a pipe containing a contraction, like Fig. 214, the pressure at the throat B is less than at the inlet A, due to the increased velocity at B. In a properly proportioned pipe this loss of pressure is almost entirely regained at the outlet C. These facts may be proved by inserting pressure gauges at A, B and C. Practically the same amount of water therefore will be delivered through such a tube as through a length of straight pipe of equal length and diameter under the same work-

ing pressure. The temporary loss of pressure at B can be measured by a U-tube containing mercury, and it is found to increase approximately as the square of the throat velocity—that is to say, if the velocity of the water at B doubles, the difference of mercury levels becomes about four times as great. Mr. Clemens Herschel in 1887 invented the Venturi meter, based upon the phenomenon above described. The Builders Iron Foundry, Providence, R. I., has perfected many different types of indicating, recording and registering instruments for use with the Venturi tube. Fig. 215 shows an indicating manometer commonly used with the meter, when used for measuring boiler feed-water.

FIG. 214.—THE VENTURI METER.

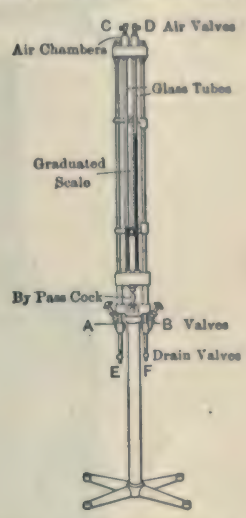

FIG. 215.—MANOMETER : . : VENTURI METER.

The V-Notch Water Meter.—When water flows over a sharp-edged V-shaped notch, whose sides are at an angle of 90°, the amount of water flowing may be computed by the formula: Cubic feet per minute $= 0.305H^2\sqrt{H}$, in which H is the height in inches of the level of still water behind the notch measured above the level of the bottom of the notch. A paper by D. Robert Yarnall, in Trans. A. S. M. E., 1912, gives the results of tests of a recording water meter made on this principle, which showed an average error of less than 0.5 per cent. Fig. 216 shaws a recording hot-water meter of this type, built in connection with a Cochrane feed-water heater, made by Harrison Safety Boiler Works. The level of the water behind the notch is transferred by a tube to the cylinder shown in the chamber at the left, which contains a float, the vertical rod from which actuates a rod on a clock recording apparatus contained in the case above.

Feed-water Indicators.—Fig. 217 shows the Pitot-tube method of indicating the flow of water in pipes. A and B are two ¼-inch tubes fixed in the pipe and bent so that the portion parallel to the axis is at the middle of the pipe and pointing opposite the direction

of flow. A is open at the end, with the orifice, a thin edge, at right angles to the axis of the pipe. B is closed at the end and has two

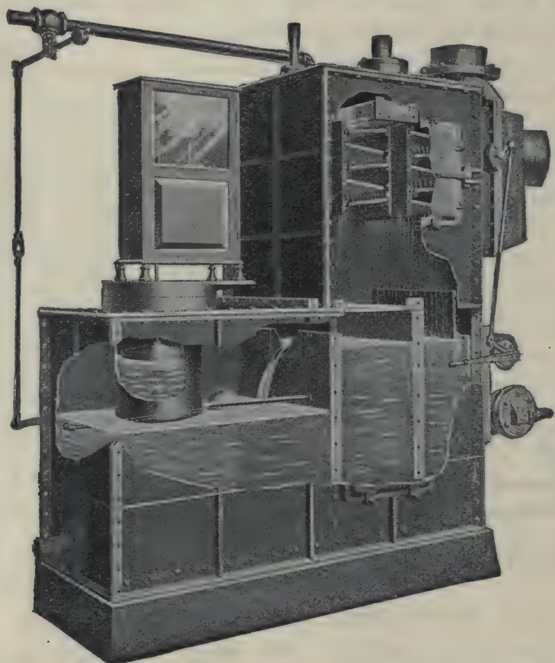

FIG. 216.—V-NOTCH METER IN A COCHRANE HEATER.

or more small holes bored in it, on each side, some distance back from the end, the face of their openings being smooth and parallel to the direction of flow in the pipe. C and D, the prolongations of these tubes, are each connected to mercury tube gauges. The gauge connected with A registers the total, or impact pressure, and that connected with B the static pressure. The difference is the velocity pressure in inches of mercury, which is converted into feet head of water by multiplying by 1.134. The corresponding velocity is found by the formula $V = \sqrt{2gH}$, but as this is the velocity at

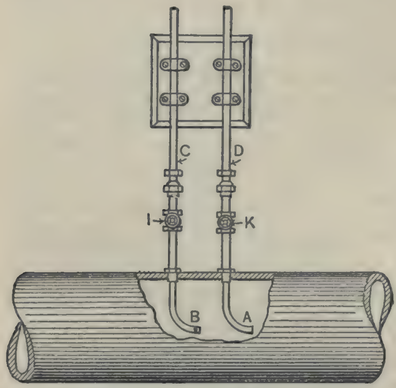

FIG. 217.—PITOT-TUBE MEASUREMENT.

the center of the pipe only it must be multiplied by a coefficient, usually from 0.87 to 0.91, which is determined by calibration with a tank.

Filtering Oil from Feed-water.—Fig. 218 shows a filter for removing oil from feed-water, made by the Ross Valve Co., Troy, N. Y. The filter is placed between the feed pumps and the boiler. It consists essentially of a chamber containing a bag made of "Turkish

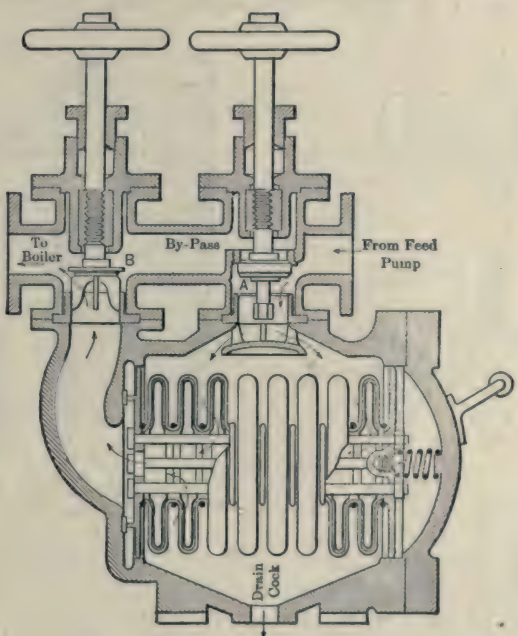

FIG. 218.—FEED-WATER FILTER.

toweling," so folded as to obtain a large area of filtering surface in a small space. The surface of the bag is formed into a series of deep circular corrugations by being thrown over a bronze skeleton, and drawn down between the sections by strings wound around it. The filtering surface is from 250 to 1000 times the area of the feed pipe, according to the service required. The threads of the Turkish toweling retain the oil until they become saturated with it, while they let the water pass through. The filter may be cleaned by reversing the direction of the current, allowing the wash water to run to waste, or by changing the filter bag, a fresh one always being kept in reserve. Pressure gauges are placed near both inlet and outlet, and when the

difference in pressure at a given rate of flow becomes excessive it indicates that the filter bag is clogged and should be cleaned or changed.

Steam Meters.—Fig. 219 shows an elementary form of indicating steam-flow meter based upon the Pitot tube. *A* and *C* are two ordinary gauge-cocks and *G* is a gauge-glass; *C* being connected with the static nozzle *S*, and *A* with the dynamic tube *D*. The height of water *H* is proportional to the square of the velocity of

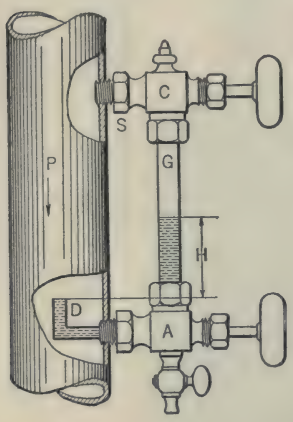

FIG. 219.—PITOT-TUBE STEAM METER.

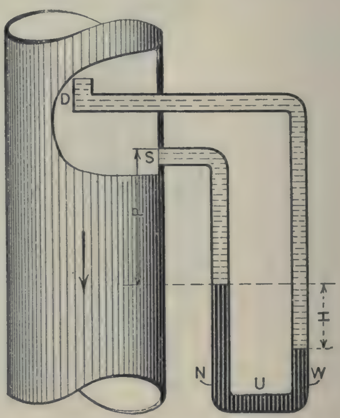

FIG. 220.—PITOT TUBE WITH MERCURY MANOMETER.

steam flowing through the pipe *P* and automatically adjusts itself to the variations in velocity; thus, for decreasing velocities, the water in glass *G* discharges through *D* until the water column *H* balances the velocity pressure in pipe *P*, and for increasing velocities, condensation from the upper part of the instrument accumulates and the water column *H* rises until a balance is effected for the higher velocities.

According to Gebhardt, this device in connection with a calibrated scale gives readings within 5 per cent of condenser measurements for continuous flow and constant pressure and quality of steam, but for varying flow and pressure its indications are not reliable. Fig. 220 shows a Pitot-tube steam meter in which a mercury manometer is used for indicating the velocity. *S* is the static nozzle at right angles to and *D* the dynamic nozzle facing the current; *U* is an ordinary U-tube manometer partially filled with mercury. When there is no flow the surface of the mercury in the columns

N and W will be on the same level and the upper portions will be filled with condensed vapor. When there is a flow, the mercury will be depressed as indicated and the difference H in the heights of the mercury columns will be a measure of the velocity of flow at the point in the pipe where the dynamic tube is placed.

This velocity may be expressed by substituting the proper values in the equation

$$V = K\sqrt{h - \frac{dm}{ds}},$$

in which $h =$ height of the mercury column H, $k =$ an experimental coefficient, $ds =$ density of steam in the main pipe, $dm =$ density of the mercury in pounds per cubic foot. The mercury manometer is less sensitive than the water manometer by $\sqrt{13.6}$ or approximately 3.7. The variable height of the water column above the mercury is included in the value of the coefficient K.

The General Electric Co. makes a number of steam meters of the Pitot-tube type. Three styles are manufactured: (1), one in which the velocity pressure is measured directly by means of a U-tube manometer; (2) one in which the variation in the height of the mercury is transmitted to an indicating dial through the agency of floats and pulleys, and (3) one in which the variation in the weight of the mercury column actuates a recording mechanism by means of a series of compound levers. A nozzle plug, shown in Fig. 221, is used in place of the ordinary static and dynamic nozzles. TT are the static openings, or "trailing set," and LL the dynamic openings or "leading set." The plug is screwed into the pipe with the "leading set" directly facing the current and the connections to the manometer are made through the openings T' and L'. The weight of steam flowing may be obtained directly from the height of the mercury column by means of suitable charts based upon experiments. Adjustment for variations in pressure, quality and pipe diameter are made by setting the chart cylinder C, Fig. 223, in accordance with the graduated scales at the bottom of the instrument.

For general purposes a revolving chart is furnished, the readings of which, multiplied by the area of the pipe, give the weight of steam flowing. For low velocities the difference in the heights of the mercury columns, if vertical, is so small as to lead to serious error; hence provision is made for this by inclining the manometer as indicated in Fig. 222. With this the actual head of mercury due to the velocity is H, but the difference in the lengths of the columns

is D. The indication on the chart corresponding to the height of the mercury in the glass T'', multiplied by a constant depending upon the inclination of the glass, is the rate of flow in pounds per hour per square inch of the pipe cross-section.

The accuracy of this meter depends upon the refinement of adjustment and the extent of error in reading the height of the mercury column. Tests of this instrument, conducted at the Armour Institute of Technology, gave readings for continuous flow agreeing

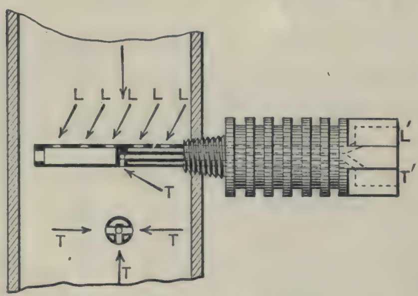

FIG. 221.—NOZZLE FOR STEAM FLOW METER.

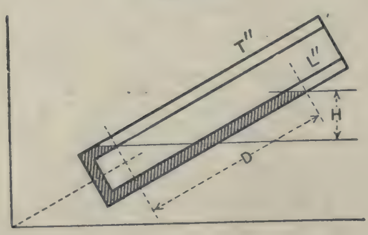

FIG. 222.—INCLINED MANOMETER.

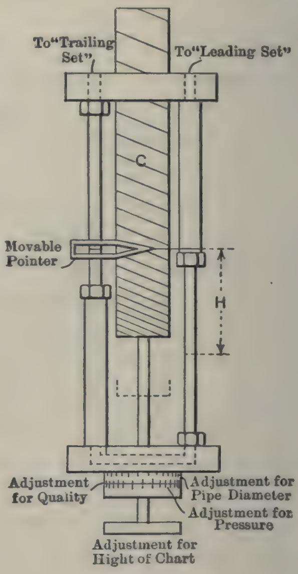

FIG. 223.—ADJUSTABLE CHART FOR STEAM METER.

within 1 to 8 per cent of condenser measurements, depending upon the rate of flow. For interrupted flow the departure from condenser readings was more marked.

Recording draft gauges on the inverted can principle (see Fig. 251, page 587), but with the can supported by a plunger floating in mercury instead of by a spring, are made by the Uehling Instrument Co.

Other steam flow meters on the Pitot-tube principle are described in Bulletin 800 of James G. Biddle, Philadelphia, 1915, and in Bulletin No. 3 of Republic Flow Meters Co., Chicago, 1914.

The St. John Steam Meter.—Fig. 224 is a meter used by the New York Steam Co. to register the steam used by its customers. The

author has used this meter to measure the steam delivered by boilers, and has also tested its accuracy at different rates of flow, by means of a surface condenser, and found it to have no error greater than that of the possible error in reading the height of the line on the paper record, say 0.01 inch, equivalent to an error of 1 per cent for 1 inch height above the zero line of the record, or 2 per cent for ½ inch height.

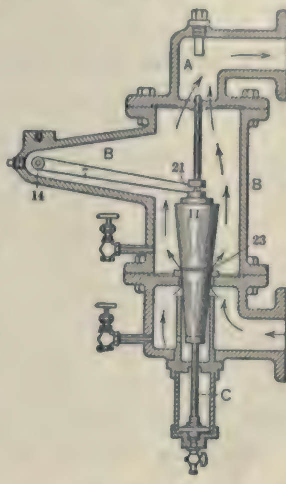

Fig. 224.—The St. John Steam Meter.

Steam enters the meter at *G*, and escapes at *H*. The tapering valve 11, with its guide rods and piston head standing vertically in casings *A*, *B*, *S* and dashpot *C*, rises and falls, stands high or low in the hole or seat 23, and increases or diminishes the annular space between the valve and seat, in accordance with the flow of steam from *G* to *A*.

As the valve rises and falls, the motion is communicated to the lever 7, by its contact with the valve at 21, and is then further

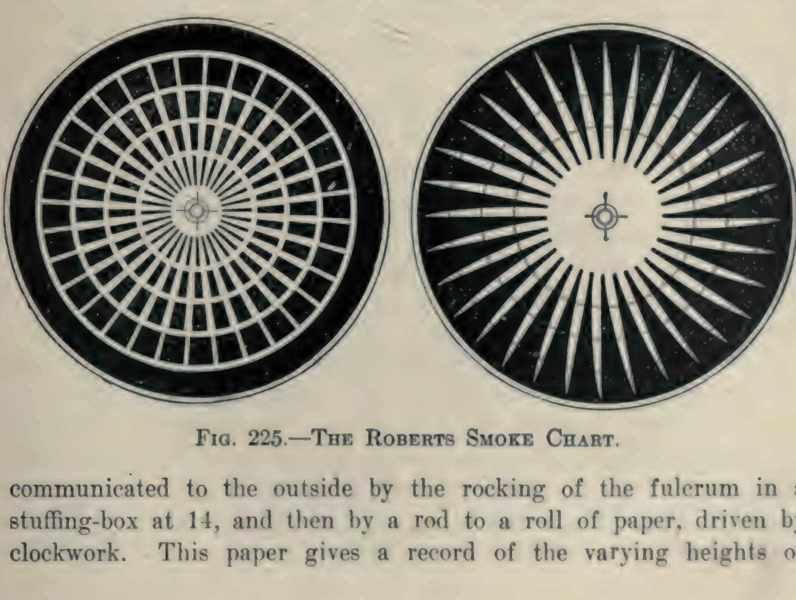

Fig. 225.—The Roberts Smoke Chart.

communicated to the outside by the rocking of the fulcrum in a stuffing-box at 14, and then by a rod to a roll of paper, driven by clockwork. This paper gives a record of the varying heights of

valve and flow of steam, which flow is proportioned to the height. The formula for computation is based on the flow of steam when the valve is one inch off the seat, which is ascertained by actual test by means of a condenser.

The Roberts Smoke Chart.—Fig. 225 shows two styles of smoke chart invented by E. P. Roberts, Smoke Inspector of Cleveland, O., which are claimed to be more convenient in operation than the Ringelmann chart. They consist of disks of cardboard having radial black lines on a white background. When a disk is revolved a series of tints appear, ranging from white at the center to black at the edge. They are spun by hand while supported on a brad-awl or other convenient spindle, an eyelet center being provided in the disk for the purpose. One of the charts, when spun, shows a series of rings corresponding to smoke densities of 20, 40, 60, 80 and 100 per cent. (For the Ringelmann chart see page 588.)

The Ellison Differential Draft Gauge is shown in Fig. 226. It consists of an inclined tube of small caliber attached to a vertical

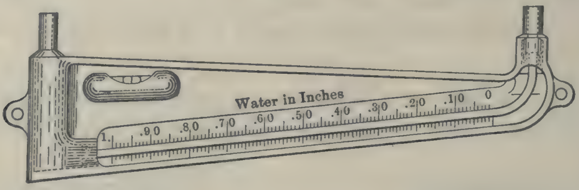

FIG. 226.—ELLISON DRAFT GAUGE.

tube of large diameter, and mounted on an aluminum case, with a graduated scale along the inclined tube. A spirit level is attached to the instrument. The liquid used is a light non-drying mineral oil (sp. gr. 0.834), and the graduations are so made that the figures correspond to hundredths of an inch of water-level. A combination gauge is also made in which the lower end of the inclined tube joins a U-tube, so that pressures up to 5 inches of water may be measured, the graduations in the U-tube being tenths of an inch.

The Blonck Differential Draft Gauge.—In a boiler plant containing several boilers it is important to know that each boiler is doing its proper share of the total work. One means of obtaining this knowledge is to have the steam pipe of each boiler equipped with a steam meter. Another means is to have a feed pipe of each boiler provided with an indicating water meter, such as the Venturi, together with a feed-water regulator to keep the water level constant.

Still another means is a differential pressure gauge which registers a difference in pressure or draft between the damper and the furnace. The area for the passage of the gases from the furnace to the flue damper being unchangeable in a given boiler, the amount of gas flowing is proportional to the velocity, and the velocity depends on the difference of pressure at the entrance and the end of the passage. If the gases were of uniform temperature and pressure, the quantity flowing would be proportional to the square root of the pressure difference. This law of proportionality is modified by variation in the temperature and density, but within the ordinary range of conditions of boiler practice it is approximately true. If the furnace conditions are constant, so that the gas always contains the same percentage of CO_2 and of O, then the amount of fuel burned in a given time is proportional to the gas volume, and the boiler capacity is also approximately proportional to it within moderate ranges of excess driving. At very high rates of driving, of course, the efficiency decreases, so that doubling the amount of coal burned will not double the amount of steam produced. Having once established by experiment the difference of draft pressure that gives a normal rate of driving of a given boiler, a differential pressure gauge will indicate whether the boiler is developing more or less than its rated capacity. Any increase in the draft between the furnace and the damper may, however, be caused by something quite different from excess rate of driving, namely, abnormal furnace conditions, such as too thin fires or holes in the fires. These conditions may be shown by a second gauge indicating the difference in pressure between the ash pit and the furnace. Having established the normal difference for a given rate of driving, a decrease in that difference means decreased resistance of the fuel bed, which may be due to thin fires or to holes, and an increase in the difference means increased resistance caused by too thick fires or fires choked by clinker coal or by caking, or grates choked by ash or clinker.

A differential pressure gauge made by W. A. Blonck & Co. of Chicago, Ill., takes the place of the two gauges above referred to, as illustrated in Fig. 227. It is called the Blonck efficiency meter.

It consists essentially of two sensitive draft gauges, the lower one filled with red oil, giving a relative indication of the pressure with which the air rushes into the furnace or the resistance of the fuel bed, while the upper gauge, filled with blue oil, gives a relative measure of the amount of combustion gases passing the boiler proper,

In addition to the two gauges the meter is provided with two sliding scales which are to be adjusted to the best and most efficient operating condition of the particular boiler. The deductions to be read from the various positions of the instrument are shown in the diagram below the illustration. In order to instruct the fireman about the correction of wasteful conditions in the fire, the sliding

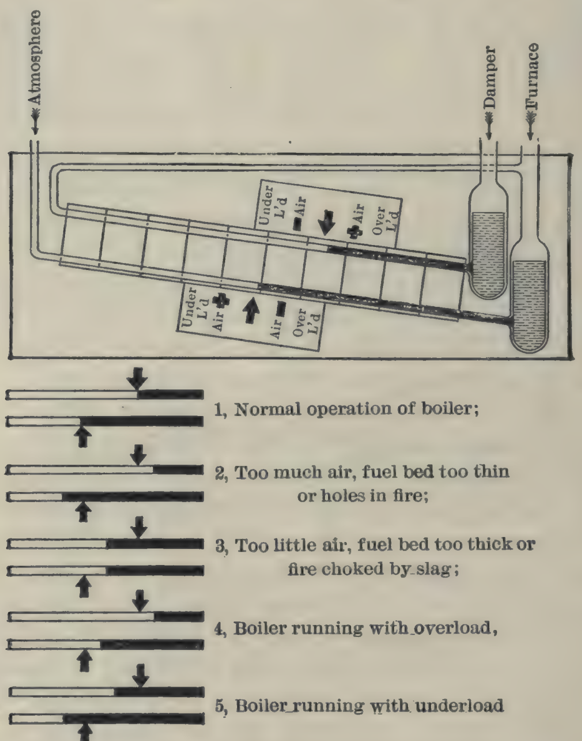

FIG. 227.—DIAGRAM OF BLONCK EFFICIENCY METER AND PRINCIPAL INDICATIONS OF THE INSTRUMENT.

scales are provided with the following abbreviations: normal position (arrow); excess air (+ air), and lack of air (— air). The connections between the instrument, furnace and boiler side of damper consist of standard ⅛-inch steel piping.

The Uehling Triple Draft Gauge is shown in Fig. 228. Attached in front of the scale in an inclined position is a large glass tube LL containing a small tube H which protudes from the tube LL at its upper

end. *H* and *L* respectively are in communication with the five-way valve *C* through the connections *D* and *K*. The valve *C* is further connected through suitable pipes *A* with the ash-pit, *I* with the furnace and *G* with gas exit between the boiler and the damper. The valve *C* is operated by a movable index *J* which revolves in front of a dial upon whch the letters *O, T, F, B* are shown. When the index points to *O, H* and *L* are in communication and the gage shows zero. When it is moved to *T, H* and *L* are in communication respectively with *A* and *G* and the gage shows the total draft between the ash pit and damper. When the index is moved to *F, H* and *L* respectively communicate with *A* and *I* and the gage shows furnace draft, i.e., the drop of pressure or resistance through the fire. If the index is moved

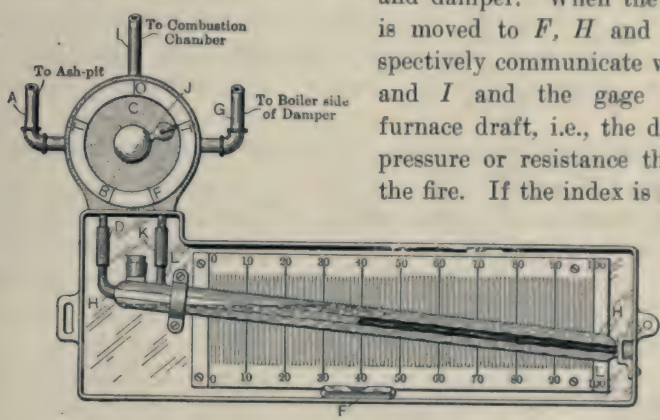

FIG. 228.—THE UEHLING TRIPLE DRAFT GAUGE.

to *B, H* and *L* respectively communicate with *I* and *G* and the gage shows the boiler draft, i. e. the drop of pressure between the furnace and the damper.

Flue-gas Analysis.—The method of analyzing flue gases by the Orsat or other instruments consists in measuring a sample, usually 100 cubic centimeters, of filtered gas at atmospheric temperature and pressure, in an accurately graduated glass vessel, called a burette, which is kept at a uniform temperature by enclosing it in another glass vessel filled with water, then passing it into a glass bulb or cylinder containing a chemical which absorbs one of the constituent gases, returning it to the burette, and measuring it again, the difference being the volume of gas removed by the absorbent. This operation is repeated with different chemicals until all the constituent gases have been removed, except nitrogen, for which no absorbent has been found.

The absorbent usually employed for carbon dioxide is a concentrated solution of caustic potash. For oxygen a solution is made of 5 grams of pyrogallic acid in 15 c.c. of water added to a solution of 120 grams of caustic potash in 80 c.c. of water. In the Hempel apparatus slender sticks of phosphorus covered with water are sometimes used instead of the pyrogallic solution. For carbon monoxide the solution is made by dissolving 10.3 grams of copper oxide in 100 c.c. of concentrated hydrochloric acid. To insure greater accuracy the gas should be passed successively through two bulbs containing this solution. The order of analysis followed is always first CO_2, then O, then CO. The anaylsis for CH_4, C_2H_4 and H is not often undertaken in connection with boiler tests. Gas analysis is a delicate operation requiring training and experience for accurate work.

Illustrations of the Orsat and Hempel instruments will be found on pages 578 and 579.

CO_2 Recorders.—A great variety of instruments for automatically analyzing and recording the percentage of CO_2 in flue gases have been placed on the market. Some of the earlier ones have disappeared on account of their complexity and the difficulty of keeping them in good working order. CO_2 recorders are now (1914) advertised by Precision Instrument Co., Detroit, Mich.; Uehling Instrument Co., Passaic, N. J., and Cambridge Scientific Instrument Co., Cambridge, England.

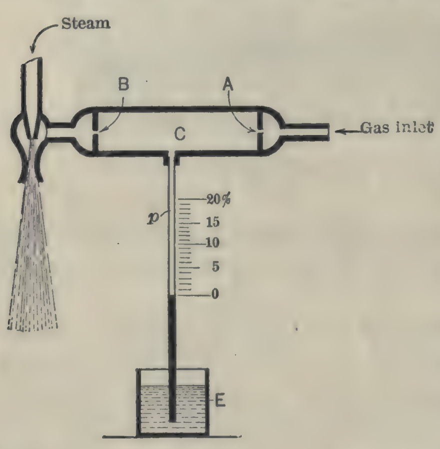

FIG. 229.—PRINCIPLE OF THE UEHLING PYROMETER AND CO_2 APPARATUS.

The principle of the Uehling instrument is shown in diagrammatic form in Figs. 229 and 230. Referring to Fig 229, the gas to be analyzed is drawn through two apertures, *A* and *B*, by a constant suction produced by an aspirator. If the apertures are kept at the same temperature, the suction or partial vacuum in the chamber between the two apertures will remain constant so long as the gas passes through both apertures; if, however, part of the gas be taken

away or absorbed in the space between the two apertures, the vacuum will increase in proportion to the amount of gas absorbed. It is evident that if a manometer or light vacuum gauge be connected with this chamber, the amount of gas absorbed will be indicated by the vacuum reading.

The diagram of Fig. 230 shows the more important parts of the complete instrument, showing the path of the gases through the filter, apertures and absorption chamber. The instrument consists primarily of a filter, absorption chamber, two apertures (*A* and *B*) and a small steam aspirator. Gas is drawn from the boiler by means of the aspirator through a preliminary filter located at the boiler, and then through other filters on the instrument, which insure that the gas flowing through the apparatus is absolutely clean and eliminate any possible clogging. The clean gas passes through aperture *A*, thence through the absorption chamber and aperture *B*, to the aspirator.

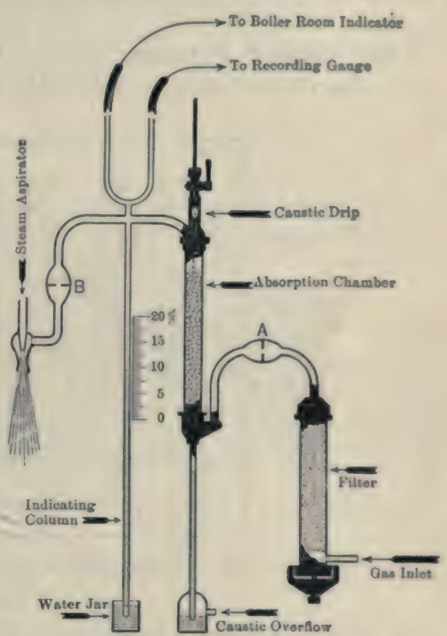

FIG. 230.—DIAGRAM OF THE UEHLING CO_2 RECORDER.

A dilute solution of caustic soda flows into the absorption chamber by gravity from a tank, through a sight-feed which is regulated by a cock as shown. The CO_2 is completely absorbed by the caustic solution as the gas flows through the absorption chamber and while it is between apertures *A* and *B* (in recent modifications of the instrument the solution is replaced by a solid absorbent). This reduces the volume and causes a change in the tension (partial vacuum) of the gas between the two apertures. This tension varies in exact accordance with the percentage of CO_2 contained in the gas, and is indicated by a water column at the instrument, which is calibrated so as to indicate directly percentages of CO_2. This

partial vacuum, or per cent CO_2, is also communicated to an indicating gauge in front of the boiler and to a recording gauge which may be located at a considerable distance from the machine. Fig. 231 is a reproduction of a tape record from a recording gauge. Circular gauge records may also be used. The lowest portion of the record shows when the firing doors were opened for cleaning fires, and the serrations in the remainder of the record show the variable conditions in the furnace as the coal burned down and fresh coal was added.

The Uehling Pyrometer.—The principle of the CO_2 apparatus above described is also applied in the Uehling pyrometer. The aper-

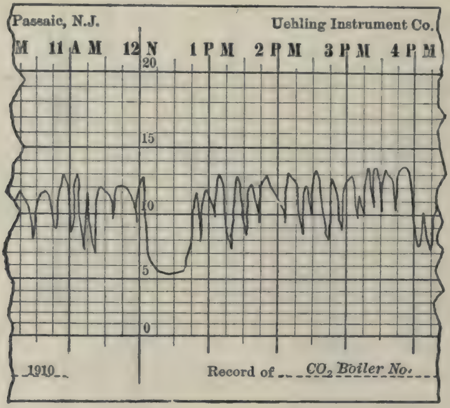

FIG. 231.—RECORD OF A CO_2 APPARATUS.

ture *A* is located in a nickel tube which is exposed to the heat to be measured, while the aperture *B* is kept at a lower temperature, usually by enclosing it in a chamber surrounded by exhaust steam at atmospheric pressure. The suction at the aspirator being constant, the partial vacuum at *C* will depend on the difference of temperatures at *A* and *B*, and this vacuum is indicated on a water gauge and also on a recording gauge as in the CO_2 apparatus, the graduations being made to record temperatures directly.

A pyrometer and CO_2 apparatus are also combined in one machine.

Piping Connections for CO_2 Recorders.—Fig. 232 shows a plan of the piping from eight boilers to a CO_2 recorder. A ½-in. pipe runs from the middle of the last pass in each boiler to a header that is located at the center of the system, and is easily accessible. The

header then runs to the recorder, which is placed in front of the boilers where the minimum amount of piping possible will reach it, and in a cool, light place where it can be easily watched. The

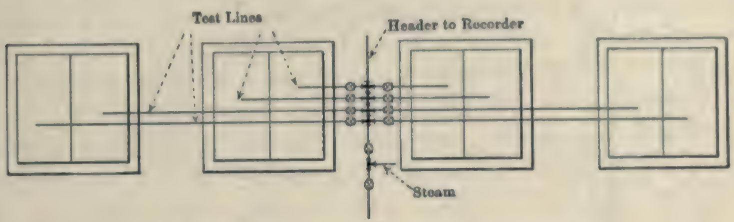

FIG. 232.—PIPING FOR CO_2 RECORDERS.

header, near the recorder, contains a filter to remove soot, and it is also provided with a steam (or compressed air) connection, used to blow deposits of soot from the pipes, and at the lowest point with a drain pipe and valve, through which the water of condensation may be drained out.

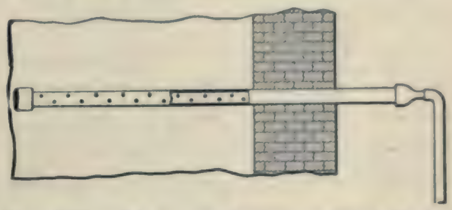

FIG. 233.—PIPE FOR SAMPLING FLUE GASES.

Fig. 233 shows a sampling pipe for collecting gases for analysis or for CO_2 recorders. From 16 to 20 ⅛-inch holes are drilled in a ½-inch pipe which is closed at the end.

A more accurate apparatus for collecting samples of flue gases, designed by J. C. Hoadley about 1885, is shown in Fig. 255. Adjoining the flue there is placed a shallow air-tight sheet-iron box, and numerous ¼-inch pipes of equal length are placed as shown in the illustration, so as to collect gas from different parts of the cross-section of the flue, and deliver them to the box, where they are mixed before being carried to the analyzing apparatus.

The Nassau CO_2 Machine.—Fig. 234 shows a CO_2 machine designed by F. F. Uehling. It is made up in a light cast aluminum case, the size of which is 3x4x12 inches. The burette *A* is surrounded by the jacket *E*, which contains a solution of acidulated methyl orange and communicates with *A* at the bottom. By blowing into the top of *E* by means of a mouthpiece *W*, through tube *G*, the liquid will be forced into the burette *A*. When *A* is full, the three-way cock *H*

is closed to A, to prevent the liquid returning to E. By actuating pump P, gas will be drawn from the boiler or flue into the tube D, through the inlet I. When the gas reaches D, H is opened so as to connect the source of the gas with the absorption chamber B through a capillary tube C. B is the short leg of a U-tube and is filled with a caustic solution and fine iron wire to provide ample surface for quick absorption. When B is connected with the source of gas through H, the absorbent will rise in C to a certain level, depending upon the tension of the gas in D. The movable index X is then shifted to coincide with this level. Cock H is then turned so as to connect D with A, and by means of the mouthpiece W, the gas is drawn from D into A until the level of the liquid in A coincides with the zero line of the scale. The burette then contains 100 volumes of the gas. Now by turning the cock H so as to connect A with B, opening the pinchcock K and blowing through W, the gas will be forced into B, where in less than 30 seconds the CO_2 in the gas will be entirely absorbed. The remaining gas is then drawn back into A until the level of the solution in B again reaches the index X. The pinchcock K is then closed and the level of the liquid in A will indicate the per cent of CO_2 absorbed.

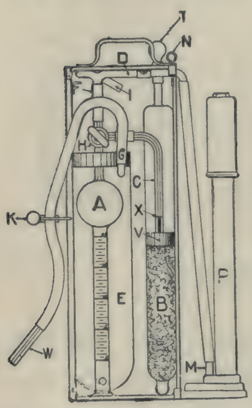

FIG. 234.—CO_2 APPARATUS.

The Bi-meter CO_2 Recorder.—This instrument is made by the Cambridge Scientific Instrument Co., Ltd., Cambridge, England. Fig. 235 is a diagrammatic sketch of the internal construction. The apparatus consists of two gas meters M_1 and M_2, an absorption box E, a water suction pump B, and a recording mechanism F, G.

The water-jet suction pump or aspirator B, with the consumption of about 6 gallons per hour, draws about $1\frac{1}{2}$ cubic feet of the flue gas through the instrument per hour. The gas, entering the recorder at D, after having first passed through the soot filter, is cooled in the first chamber of the cooler K, and is then measured in meter M_1. The CO_2 is then extracted from the gas in the absorption chamber E containing lime; and, since during this chemical process the remainder of the gas becomes heated, it is again cooled to its former temperature by being passed through a second chamber of the cooler K. From the cooler the gas is led to the second meter M_2 to be

again measured, and is then allowed to escape into the atmosphere by way of the aspirator B and the water vessel C.

The water which is employed for the working of the instrument enters at inlet A, and flows through the cooler K into the aspirator B. It there draws in the flue gas, and the mixture of water and gas passes into the water vessel C. From this the water escapes through an overflow drain pipe H, and the gas bubbles into the atmosphere.

The two gas meters are partially filled with oil, and are so arranged that, when no absorption takes place, the meter M_2 runs about 4 per cent slower than the meter M_1. Thus when no CO_2 is ab-

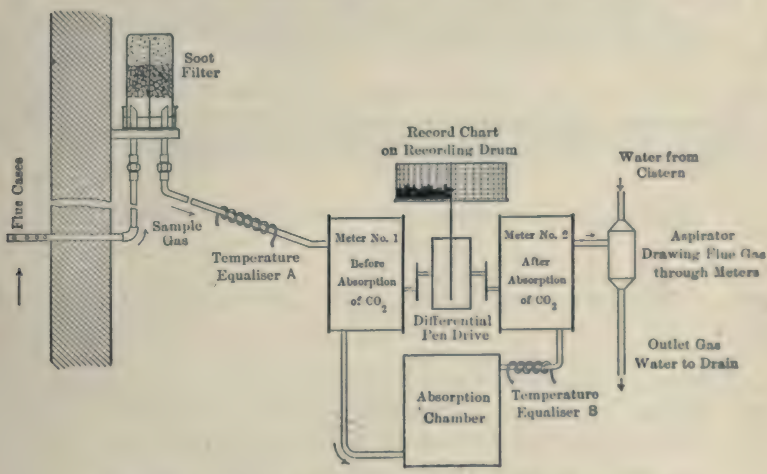

FIG. 235.—DIAGRAM OF THE BI-METER CO_2 RECORDER.

sorbed the pen is made to record lines about 3 or 4 mm. in height, and adjustment must be made so that the upper ends of these "zero" marks should lie on the zero line of the chart. When this is secured, the apparatus, on connecting up the absorption chamber in position, records the percentage of CO_2 contained in the gases which are under test.

The recording pen is actuated by means of a differential drive F, operated by meters M_1 and M_2. On an average from 20 to 25 analyses may be recorded per hour, the number being dependent upon the volume of the flue gases pasing through the instrument. This number may be reduced by adjustment of a cock P placed in the gas passage near the aspirator B.

Oxygen Recorder.—An oxygen recorder would be even more useful

than a CO_2 recorder, but at this date (1914) no such instrument is on the market. The author has suggested that the bi-meter recorder could be used for this purpose, using phosphorus as the absorbent.

Superheating of Steam.—The use of superheated steam at a temperature of about 500° F. has become almost universal in large power plants since the introduction of the steam turbine. In addition to the lessening of the steam consumption, the use of superheated steam increases the life of the buckets of the turbine by avoiding the erosion which is due to water in the steam. In regard to the saving of steam due to superheating, the following figures are given in a catalogue of Power Specialty Co., makers of the Foster superheater.

A 3300 H.P. Lenz cross-compound engine having 37½-in. and 63-in. diameter cylinders, 55-in. stroke, at Charlottenburg, Germany, with 192 lbs. gauge pressure, 26-in. vacuum, 107 revs. per min., gave the following steam consumption:

Temp. of Steam.	Sperheat.	Load..............	1/4	1/2	3/4	1/1	5/4
570°	185° F.	Steam per I.H.P. hr., lbs......	11.1	10.1	9.5	9.2	9.7
660°	275° F.	Steam per I.H.P. hr., lbs......	10.6	9.7	9.0	8.8	9.2

The saving in steam effected by superheating 100°, as compared with saturated steam, is, approximately, for steam turbines, 10 per cent; triple-expansion engines, 12 per cent; compound engines, 14 per cent; simple engines, 18 per cent and over.

Tests of Buckeye engines, simple, 12x16-in., and compound 10 and 17½x16-in., with steam at 100 to 110 lbs. pressure, gave the following:

Engine.	Per cent of Rated Load.	Degrees of Superheat.				
		0	50	100	150	200
		Lbs. Steam per I.H.P. Hr.				
Simple, non-condensing.........	30	35	28	24	21.5	19.5
Simple, non-condensing.........	50	31.5	25.5	22	19	17.5
Simple, non-condensing.........	100	28.5	24.0	20	18	17.5
Compound, non-condensing......	100	....	....	17.5	15.5	14.6
Compound, condensing..........	100	18	16.5	14	12.5	11.5

The Foster Superheater.—This superheater consists of a series of straight seamless drawn steel tubes, expanded at one end into steel manifolds or connecting headers, and at the other end into return headers, or return bends. One element, with a return bend, is shown in Fig. 236. On the outside of each tube is fitted a series of cast-iron annular gills or flanges, bored to gauge and shrunk on to the tube so as to be practically integral with it, at the same time exposing an external surface of cast iron, which metal is best adapted to resist the action of the heated gases. The mass of metal in the tubes and covering acts as a reservoir for heat, which is imparted to

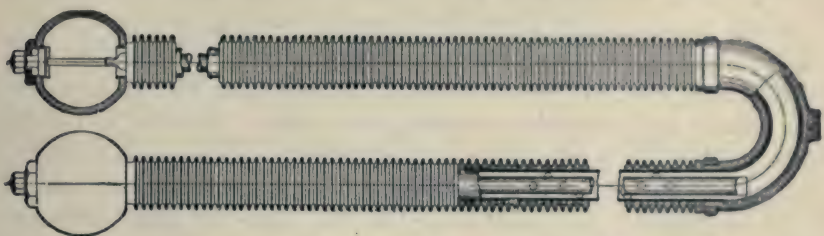

FIG. 236.—RETURN BEND ELEMENT AND CONNECTING HEADERS OF A FOSTER SUPERHEATER.

the steam evenly, tending to secure a constant temperature of steam in spite of fluctuations in the temperature of the hot gases. Inside of the elements there are placed other tubes of wrought iron, which are centrally supported by means of knobs or buttons regularly spaced throughout their length. These inner tubes are closed at the ends. A thin annular passage for the steam is thus formed between the inner and outer tubes.

The superheater is designed with a view to avoiding the necessity for flooding devices or any form of connection between the water space of the boiler and the superheater. The protection afforded by the external covering of cast iron is ample to prevent damage to the surface during the process of steam raising.

CHAPTER XV.

BOILER TROUBLES AND BOILER USERS' COMPLAINTS.

It is the experience of every large boiler-making concern that of all the boilers it sells, a certain proportion are, shortly after erection, complained of by the purchaser as being unsatisfactory. When such complaints are received, an expert in boiler-testing and management is usually sent to make an investigation, and, if possible, to remedy the trouble. In most cases he succeeds, after a great deal of difficulty, in satisfying the purchaser, either by improving the conditions of the running of the boiler or by showing that the boiler is not to blame for the trouble; but sometimes he fails, and the matter is finally adjusted by the boiler being taken out, by a reduction in the price, or by recourse to arbitration, or to a law-suit. In a law-suit the boiler-maker usually wins, for the reason that a boiler-maker, having had previous experience in such matters, is not apt to go to law unless he has a very strong case. The purchaser, of course, also thinks he has a strong case, but he is apt to be not well posted on the law of contracts, and his attorney is apt to be ignorant of the amount of evidence which the boiler-maker will bring forward on the trial, and therefore underrates the strength of the boiler-maker's side of the case. It is the object of this chapter to discuss, not the troubles and complaints concerning boilers in their relation to possible law-suits, but those that may be avoided or remedied by good engineering.

The complaints from boiler-users concerning new boilers may be divided into three general classes: 1, Low capacity; 2, Structural defects, such as leaks, burnt tubes and plates, etc.; 3, Poor economy. The last is not often a cause of complaint, because the great majority of boiler-users make no tests to determine economy, and therefore if their boilers should be deficient in economy, they are ignorant of it. But if a boiler does not give the amount of steam that is needed from it, or if it leaks, the trouble is apparent at once and complaint is made immediately.

The most common causes of complaints and troubles are the following:

1. Poor draft.
2. Insufficient grate surface.
3. Poor coal.
4. Furnace not adapted to kind of coal.
5. Bad setting of boiler.
6. Leaks of air through brick-work.
7. Improper firing.
8. Insufficient heating surface (boiler too small).
9. Bad water.

We will now discuss these causes of trouble, and their remedies, in the order named.

Poor Draft.—This is a relative term; what is poor draft for one set of conditions is ample draft for another. The proper force of draft for a given case, measured at a point between the damper in the flue and the boiler itself, may be as low as ¼ inch of water-column, and in another case over 1 inch may be required, depending on the type of boiler, on the area and the course of the draft-passage through the boiler, on the area of grate surface, on the style of grate-bars, and on the kind of coal. The immediate effect of poor draft is insufficient coal-burning capacity. The first test to be applied to discover whether or not the draft is insufficient is to weigh the coal burned in each hour during the period between two cleanings of the grates, and to compare the amounts burned each hour with the amount which a calculation shows should be burned to evaporate the desired amount of water. Thus, suppose that it is expected that the boiler should evaporate 3500 lbs. of water per hour, and the temperature of feed-water, the steam-pressure, and the quality of coal are such that 7 lbs. of water should be evaporated per pound of coal, then the coal-burning capacity should be not less than 500 lbs. during each hour between cleanings. If 200 lbs. is used in the first part of the test to build up the fire, and an equal amount is burned down at the close of the test, in order to have a thin bed of coal for cleaning, then a five-hours' record of coal fed between cleanings should show approximately 700, 500, 500, 500, and 300 lbs. If the record gave 600, 400, 400, 400, and 200 lbs. it would indicate insufficient draft for the kind of grate and the kind of coal. If, however, it should show 700, 500, 400, 300, 200 lbs., it would indicate that the draft itself was ample, but that the grates were being gradually choked by ashes and clinkers.

In the second case, in which the coal is burned steadily at the rate of 400 lbs. of coal per hour, when 500 lbs. is required, the remedy indicated is an increase of the draft. It will often happen that such remedy can easily be given by a slight change in the flue-connection between the boiler and chimney. Right-angled bends in this flue-connection are exceedingly common, and they frequently cut down the force of draft at the boiler to one-half of that in the chimney. Whenever possible they should be changed to long easy curves. When two or more adjoining boilers deliver their gases into one horizontal flue, the area of this flue should increase as it travels from the most distant boiler to the chimney, the connection from each boiler to the flue should be a curved one, and the flue itself should enter the chimney with an ascending curve. Before making the changes here suggested, the existing draft in the chimney, at various points in the flue, and at each boiler, should be tested by a U-tube draft-gage. If there are no defects in the flue-connection, the next remedy to be applied is an increase in the height of the chimney. If this is not feasible, and a reference to a table of proportions of chimneys shows that the chimney has not sufficient area for the amount of coal to be burned, then a new chimney with larger area is required. In case it appears that the chimney is of sufficient area and its height cannot be increased, a remedy may be found in enlarging the area of grate-surface or in using a different kind of coal.

If the test of the coal-burning capacity shows a decreasing rate of burning, such as 700, 500, 400, 300, and 200 lbs. per hour, indicating a gradual choking of the grate by clinker, the most obvious remedy is the use of a shaking-grate, by which the accumulation of ashes and clinker may be prevented. Such a grate will sometimes increase the capacity of a boiler as much as 30 per cent, although its use may entail a loss of economy of 2 or 3 per cent due to the coal shaken into the ash-pit with the ashes. A change of coal from a clinkering to a non-clinkering variety will sometimes prove a sufficient remedy.

With a clinkering coal, increase of draft is sometimes of no benefit in increasing the capacity of a boiler, but rather the reverse; for when the fire is freshly cleaned, a strong draft with such coal causes at first a rapid combustion, resulting in high temperature and a fusing of the clinker, which soon obstructs the passage of air through the grates, checking the combustion. Enlargement of the grate surface and a slower rate of combustion per square foot of grate are then the

proper remedies, and if these are impracticable, then shaking-grates should be used. The tendency to form clinker may sometimes be lessened by blowing a little steam under the grate-bars, or by letting a little water run into the ash-pit. The evaporation of the water helps to cool the grate-bars.

When the grate-surface and the draft are adapted to the kind of coal that is being used, but it is desirable to use a poorer grade of coal on account of its low price, and the available draft pressure is insufficient to burn this coal at the required rate, the remedy is either to enlarge the grate surface or to use forced draft, or both.

Insufficient Grate Surface, and Poor Coal.—These two causes of trouble may be considered together, as they are co-related. Insufficient grate surface for one grade of coal may be ample for another grade. By grade of coal here is meant its quality as regards amount of ash and kind of ash. If the percentage of ash in the coal is low, and it is low in iron and sulphur, which are the principal causes of clinker, a relatively small grate surface and a strong draft may be used, such, for instance, as to cause the burning of as much as 20 lbs of anthracite, 25 or 30 lbs. of semi-bituminous, and 30 to 40 lbs. of bituminous coal per square foot of grate per hour; but if the ash is excessive, or if it forms clinker, then a large grate is needed, so that these rates of combustion may be reduced 30 to 50 per cent.

Furnace Not Adapted to Coal.—Forty or fifty years ago it used to be the custom to set boilers with the grate-bars near to the shell of the boiler, 12 to 15 ins. being a common distance, the idea being that there was a loss of radiant heat if the boiler was removed a greater distance from the grate. The idea was erroneous, as may be learned by considering the question "If the heat is lost, where does it go?" A pound of coal, in burning under a boiler, generates so many heat-units. A small fraction of them is lost through the side walls of the furnace. The heat radiated into the side walls is radiated back again to the fire, to the heating surface of the boiler, to the particles of carbon in the flame, and to gaseous products of combustion, and it finally all gets into the boiler except that which is carried out of the chimney or through the walls of the setting. With dry anthracite coal, which burns practically without flame, almost any kind of furnace is a good one, but a furnace in which the grate is 12 or 15 ins. from the boiler is entirely unsuited to the burning of bituminous coal. A distance of from 3 to 4 feet from the grate to the boiler is now common practice for bituminous coal. With very smoky coal, 5 feet is

sometimes used; and 6 or 8 feet would be better.* With lignite, wet refuse lumber, tan-bark, bagasse, etc., 10 feet or more may be used with advantage.

A furnace for a steam-boiler is not adapted to the coal whenever the flame from the coal is extinguished by the comparatively cool surfaces of the boiler, and whenever it is not possible by skilful operation of the furnace to prevent smoke escaping from the chimney. A smoky chimney is proof either of an improper furnace for the kind of coal or of unskilful firing, or both; usually of the former.

The loss of economy and the diminution of capacity of steam-boilers due to smoky chimneys is usually under-estimated. It is stated that it has been found by experiment that the amount of soot actually present in smoke is less than one per cent of the weight of coal burned. Numerous experiments have shown also that when "smoke-consumers" are applied to a steam-boiler, while the smoke may be prevented, no gain in economy follows. This may be quite true, but the "smoke-consumers" referred to usually effect the smoke-prevention by means of an excessive supply of air, which involves waste of fuel, so that the failure to show a gain in economy is due to substituting the waste due to excessive air-supply for the waste due to imperfect combustion.

While it may be true also that the soot in smoke represents only one per cent of the fuel burned, this is not the only loss of fuel which attends the smoky chimney, for the smoke not only contains soot, but it may also contain invisible hydrocarbon gases distilled from the coal, and carbon monoxide produced in the furnace by imperfect combustion of the carbon.

Bad Setting of Boiler.—If the type of setting is one adapted to the kind of coal, it may still have errors of design or of construction which may lead to the loss of economy or of capacity, or of both. Examples of such errors are: (1) Boiler set too close to the grate. (2) Insufficient area through the flues, damper, or other passages for the gas. (3) Excessive area of gas-passages, so placed that the gases can find a path of least resistance along or across the heating surfaces, and thus be "short-circuited." The error of the boiler being set too close to the grate has already been discussed. Insufficient area of gas passages

* In the most recent practice these figures are often greatly increased. As much as 14 feet has been used with the Babcock & Wilcox type of boiler, and with the Stirling type as much as 28 feet from the level of the grate to the point where the gases flow into the bank of tubes near their upper end.

acts to choke the draft and restrict the coal-burning capacity, just as do insufficient chimney area or height, and insufficient grate area. Whether or not the gas-passages are insufficient in area can usually be determined by inspection and comparison of their measurements with that of the chimney and grate. A draft-gage should be applied at different points in the gas-passages, between the chimney and the furnace, in order to find whether there is any serious choke in the draft. This should be done when the fire is clean and burning brightly.

Whether or not the areas of the gas-passages are too large, or such as to allow of short-circuiting of the gases, is usually a rather difficult matter to determine. The error may be suspected to exist whenever it is found by an evaporation-test that the boiler gives a lower result than should be expected under the conditions, and at the same time there is found a high temperature of the chimney-gases and a low rate of evaporation per square foot of heating surface. This same set of combined conditions, viz., low capacity, low economy, and high temperature of chimney-gases, may, however, be the result of imperfect combustion in the furnace and burning of the gases in the gas-passages between the furnace and the chimney. If there is no evidence of imperfect furnace-conditions and of the burning of gas in the passages, then short-circuiting of the gases is probably the cause of the observed results. After making the diagnosis of short-circuiting, another test of the boiler should be made, if sufficient draft is available, at a very much higher rate of combustion. If it is found that this test gives an increase of economy with no increase in the temperature of the chimney-gases, this would tend to prove that short-circuiting existed during the first test. The gases may short-circuit during the test at a low rate of driving and not during the other test, because in the first test the volume of gases is relatively small, and in the second it is large, so that they completely fill the passages. The gas-passages may, therefore, be properly proportioned for a high rate of driving, but may be too large for a low rate.

Another kind of test which may be applied to determine whether or not there is short-circuiting of the gases, is the exploration of various portions of the gas-passage by an electric pyrometer, in order to discover if any portion is not swept by the current of hot gas. It is highly probable that many of the very low economic results sometimes obtained in boiler-tests, which are unexplained by the observed conditions, are due to this short-circuiting, the existence of which may be revealed by the electric pyrometer.

When the short-circuiting of the gases is proved, the remedy is obviously to change the areas of the gas-passages, or to place baffle-plates or retarders in them, so as to partially obstruct those portions of the passages where the gases tend to travel with the greatest velocity, and compel them to travel at a uniform rate across or along the whole extent of heating surface.

Leaks of Air through Brickwork.—If there are any large air-leaks through the brickwork, they can usually be discovered by inspection. There are two methods of making examinations for small leaks; first passing the flame of a candle over all the joints of the brick-work and noting where it is drawn inwards by the draft; second, firing a few shovelsful of smoky coal while the damper is shut. The smoke will then be driven out through any crevices that may exist. The existence of air-leaks in the brick-work beyond the furnace may be inferred from the results of a boiler-test, if these results show low economy together with low temperature of the chimney-gases and apparently good furnace-conditions, insuring complete combustion. If the coal is thoroughly burned in the furnace, then low economy is usually accompanied with high temperature of the chimney-gases, caused either by insufficient extent of heating surface or by short-circuiting of the gases, but if the temperature of the chimney-gases is low, economy also being low and furnace temperature high, this would indicate that the gases have been cooled by the cold air entering through leaks in the brick-work. Chemical analysis of the gases also furnishes a means of proving the existence of air-leaks. Samples of gas are taken simultaneously from a point near the furnace and from a point near the damper. If the latter sample shows on analysis a greater percentage of free oxygen than the former, it proves the admission of air into the gases between the points from which the two samples are taken.

If the supply of air to the coal in the furnace is sufficient to insure complete combustion, any additional supply, either in the furnace or through leaks in the brick-work into the gas-passages, tends to decrease the economy of the boiler. It cools the gases, decreasing the difference between the temperature of the gases and that of the water in the boiler, upon which difference the transmission of heat through the heating surface depends, and the excess of air supply finally escapes at the temperature of the chimney gases, thus causing a direct loss of heat. If, however, the supply of air in the furnace is insufficient to thoroughly burn the coal, a slight leak of air through the brick-work may be of actual benefit in supplying sufficient air to burn the un-

burned fuel gases in the gas-passages, although this air had better be introduced into the furnace itself.

In well-constructed brick-work settings, with all cracks in the joints carefully plastered, the amount of loss of heat due to leaks of air is probably very small, but large cracks may cause a serious loss of economy, and they should be looked for carefully and stopped if found.

Improper Firing.—Improper firing is probably the most common of all the many causes of poor economy of steam-boilers. Sometimes the fact that an improper method of firing is used can be learned by simple observation, but oftener it can only be known after making a series of systematic experiments. There are some kinds of firing, practiced by ignorant or negligent firemen, which any one who knows anything of the subject can say at once are wrong. Among them are: (1) Putting a large quantity of coal in the furnace at a time, covering the bed so thickly that the air-supply is choked and incomplete combustion necessarily takes place. (2) Firing at irregular intervals and occasionally allowing the bed of coal to burn so low that a great excess of air passes through it. (3) Neglecting to cover the whole of the grate surface, and allowing holes to form in the bed of coal.

There are other errors of firing which are not evident on ordinary inspection, which may be practiced by the most careful and intelligent firemen without any suspicion that they are wrong, and which can only be discovered by making a series of boiler-tests or by analysis of the chimney-gases. Such errors are the carrying of a bed of coal either too thick or too thin for the size of coal and the force of draft, and unskilful regulation of the draft. The best method of firing is such a method as will cause the chimney-gases to contain no carbon monoxide, hydrogen, or hydrocarbon gases, and at the same time to contain not more than about 6 per cent of free oxygen. The presence of combustible gases, even in small quantity, in the chimney-gas is proof of imperfect combustion and consequent loss of economy. The presence of from 3 to 6 per cent of free oxygen in the chimney-gas is usually a necessary accompaniment of complete combustion, but a greater quantity of free oxygen means an unnecessarily large supply of air, and consequent unnecessary loss due to carrying the excess of heated air into the chimney.

The percentage of carbon dioxide in the gas is of itself not as good a criterion of the furnace-conditions as the percentage of oxygen.

The following figures, taken from the table on page 28, show that low CO_2 is compatible either with a great excess or with a great de-

ficiency of air, both conditions giving low economy; also that the CO_2 may be high, over 16 per cent, either from ideal conditions, 25 per cent excess air-supply and 4.17 O in the gas, or from conditions that are far from ideal, with a deficient air supply, as shown in the third line of figures:

	CO_2.	CO.	O.	N.	Loss Due CO. B.T.U. per Lb. C.
30% deficit in air supply........	10.94	16.41	0	72.65	6090
20% " "	14.87	9.91	0	75.22	4060
10% " "	18.12	4.53	0	77.35	2030
25% excess air.................	16.69	0	4.17	79.14	0
50% "	13.91	0	6.95	79.14	0
100% "	10.43	0	10.43	79.14	0

Knowing that the best furnace-condition, the one that will give maximum economy, is one that will cause the chimney-gases to contain from 3 to 6 per cent of free oxygen, how is this condition to be secured?

If anthracite coal is the fuel, there are at least three variables which enter into the problem: (1) The size of coal. (2) The thickness of bed. (3) The force of the draft. If we consider the size of the coal to be fixed by the condition of the market price or other circumstances, then there are two variables under control at the will of the fireman, viz., the thickness of bed, and the force of the draft. Sometimes the latter is beyond his control, as when the plant is being driven to its full capacity and the draft is limited by the size of the chimney, the damper area, the areas of other gas-passages, etc., but this is a fault in the plant which should not exist. The chimney ought always to have a capacity for giving a force of draft in excess of that ordinarily needed, so that the draft of each boiler may be regulated by its damper. If both the thickness of the bed and the force of draft are under control of the fireman, he may obtain good results with either thin, thick, or medium fires, provided the force of the draft is regulated in proportion to the thickness of the fire. No rule can be given for this regulation that will be of any service. Each engineer in charge of a plant must determine for himself, by experiment or observation, the conditions of thickness of fire and the force of draft that will give the best results with the kind of coal he is using.

In a plant containing two or more boilers connected with a single

horizontal flue leading to the chimney, unless the draft of each is carefully regulated by a damper, the force of draft at each of the different boilers may greatly vary. If the force of draft at the several boilers cannot be equalized, then the thickness of coal-bed under each boiler should be regulated in proportion to the draft of each.

The attention to the proper regulation of the thickness of the bed of coal to the force of the draft, which is here recommended, may seem to be an unnecessary refinement, involving more trouble than any value that may be gained from it, but if a saving of only 1 or 2 per cent may be made thereby, is it not worth the trouble?

There are almost no records of experiments available to show the relative results obtained by different methods of firing anthracite coal, but there are hundreds of records of tests with anthracite coal showing differences of economy of over 20%, which differences are not satisfactorily explained by differences in the type or proportions of boiler, in kind of coal, rate of driving, or in anything else in the record. It is highly probable that many of the low results are due to improper regulation of the thickness of the fire. If such low results are obtained in boiler-tests, in which efforts are made to obtain good results, it is probable that much lower results are obtained in every-day practice, in which boilers are fired year in and year out without any tests being made to determine their economy.

A notable result of the loss due to improper firing is shown in the report of Prof. Walter R. Johnson of the tests he made for the United States Navy Department in 1842 and 1843.* He tested seven different anthracite coals, six of them giving an evaporation ranging from 11.15 to 11.59 pounds, averaging 11.42 pounds of water from and at 212° per pound of combustible, and the seventh, a Lehigh coal, only 10.26 pounds, or over 10% less than the average of the other six coals. Prof. Johnson, in his report, gives no hint of the real reason why the Lehigh coal gave such a low figure, but he gives an analysis of the chimney-gases which shows the extremely low figure of 4.57 for the percentage of carbon dioxide, and the very high figure of 16.7 for the percentage of oxygen. From this analysis he calculates that 47.9 pounds of air were required to burn one pound of the fuel, an amount which is more than double that required to burn the other coals. He says that the large proportion of unchanged air in the chimney-gases is probably due in some degree to the obstruction which the air

* *Engineering and Mining Journal*, October 24 and 31, 1891.

meets in arriving at the surface of the coal, from the coat of ashes which covers its surface during its combustion. He explains the existence of this coat of ashes forming on this coal more than on all others, as being due to the purity of the ashes themselves, which hinders their vitrification and flowing away.

The true reason of Prof. Johnson's low results with this Lehigh coal is no doubt that he used too thin a bed of coal on the grate for the amount of draft he had. The rate of combustion was very low, 6.52 to 7.71 pounds of coal per square foot of grate per hour, or only half of that commonly used in good modern practice. If he had attempted to increase the rate of combustion by increasing the draft, leaving the thickness of the bed the same, he might have chilled the fire so as to put it out, but if he had thickened the bed so as to offer more obstruction to the passage of air through it, he might have obtained from the Lehigh coal as good a result as he did with other coals.

The difficulties met with in obtaining the proper proportion of thickness of bed to force of draft with anthracite coal are increased when we have to deal with bituminous coal, since there are other variables in the problem besides those of size of coal, thickness of bed, and force of draft. Chief of these is probably the varying rate of distillation of moisture and volatile matter, which exists not only with different coals, but with the same coal during the intervals between firings. With the highly volatile coals of Illinois, when fired by hand, a perceptible change in the furnace conditions is made every minute. Immediately after firing, the supply of air through the grates is too little to burn the gases that are being distilled; a few minutes later, when the gases have all been driven off, the air supply is apt to be excessive, and this supply increases the longer the time which elapses until the next firing. With such coals, burned in ordinary furnaces, with hand-firing, it is scarcely possible to obtain an efficiency as high as 60% of the heating value of the coal, while with anthracite coal 75% is not uncommon. By a series of experiments, checked by analyses of the chimney-gases, it is possible to arrive at almost ideal furnace conditions, and hence to discover the proper method of firing of anthracite coal, but with bituminous coal it is impossible; and hence, with this latter coal in ordinary furnaces all kinds of firing by hand are improper; some may be worse than others, but they are all bad. Millions of tons of coal are wasted every year in the bituminous coal districts by improper kinds of furnaces and improper firing.

Remedies, however, are available in improved styles of furnace, in mechanical stoking, and in regulation of the air supply in accordance with the indications of apparatus for analyzing the flue gases.

Insufficient Heating Surface.—A common complaint made by the purchaser of a new steam-boiler is "The boiler does not make enough steam." The complaint requires an immediate investigation, and an evaporation test should be made to determine how much steam it actually makes. The boiler has probably been guaranteed to make a certain amount, say 3 or 4 pounds per hour for each square foot of heating surface. If the test shows that it makes less than this amount, the trouble will usually be found to be not insufficient heating surface, but either deficient draft, insufficient grate surface for the kind of coal used and for the draft available, choking up the grate by clinker, or short-circuiting of the gases. The remedies to be applied are such as will insure the burning of sufficient coal and such an arrangement of the gas-passages as will prevent the short-circuiting. If, however, the boiler is found to be evaporating the amount of water guaranteed, the seller is relieved of his responsibility, and he may properly tell the purchaser that the heating surface is insufficient, or in other words, that the purchaser bought too small a boiler. The purchaser may reply to this that he has other boilers which are evaporating from 6 to 8 pounds of water per hour per square foot of heating surface, and an evaporation test may show that his statement is correct. It is very apt to show also, however, that the boilers which are driven at this rate are wasting fuel by being overdriven. The purchaser then has the option of taking means, such as increasing the area of the grate surface and the force of draft, which will cause the new boiler to burn more coal and so drive it up at the rate of 6 or 8 pounds per hour per square foot of heating surface, thus wasting coal, or of buying additional boilers sufficient to give the required amount of steam at the rate of 3 or 4 pounds, and thus saving fuel. Whether he will do the one or the other will depend on the price of coal and whether the saving will warrant the extra investment. The general relation of rate of driving to economy of fuel varies so greatly with different circumstances that it is advisable in each case of the kind under consideration to make a series of tests to determine this relation for a particular plant before deciding whether to purchase additional boilers or to drive those already in place at a more rapid rate.

If a test is made of each boiler in the plant under regular working conditions it will sometimes be found that no two of the boilers are

driven at the same rate, and that an equalizing or regulation of the draft at the several boilers will effect an important saving of fuel and may increase the total capacity so as to make the purchase of additional boilers unnecessary. The author once made a test of three boilers in the same plant. The first was a long distance from the chimney; it had a small grate and large heating surface, and the draft was insufficient to cause it to develop its rated capacity. The second had a very large grate surface, was close to the chimney, had a powerful draft, and was developing double its rating, while wasting 30% of the fuel as compared with the other boilers. The third was between the other two in location; the size of grate and draft were so related to each other that it developed a little more than its rating and gave a very high economy. The evident remedy in this case was to cut down the grate surface and check the draft in the second boiler, and to increase both the grate surface and the draft in the first boiler. The total horse-power developed by the three boilers would then be the same, but about 10% of the fuel would have been saved, and by then increasing the draft on all the boilers a greater horse-power could be developed with the original consumption of fuel.

Insufficient heating surface is a most serious evil, and it is often unsuspected if evaporation tests are not made. It is always the cause of waste of fuel, but if the boilers give all the steam that is desired, the grate surfaces, draft and quality of coal being such that the boilers may be driven far beyond their economical rating, their waste of fuel may never be discovered, because they are never tested.

Bad Water.—The troubles arising from the character of the water used for steam-boilers are of three different kinds: 1, foaming; 2, corrosion; 3, incrustation or scale. Sometimes all these troubles exist at the same time.

Cause of Foaming in Boilers.—Boilers foam on the introduction of alkaline water only because the alkali throws into suspension the calcium and magnesium compounds originally dissolved in the water and also much of the scale attached to the tubes and sheets of the boiler. Under ordinary conditions of service, boiler foaming takes place only in the presence of particles of matter suspended in the water in the boiler. In the laboratory, boiling distilled water does not foam on the addition of pure sodium carbonate, but does foam vigorously on the introduction of some fine insoluble powder such as calcium carbonate or magnesia alba. (C. Herschel Koyl, *R. R. Gazette,* June 13, 1902.)

The remedies for foaming are: filtration of the water to remove suspended matter; chemical treatment to neutralize some of the free alkali and subsequent filtration; the use of a surface blow-off.

Corrosion is due to the presence in the water of some oxidizing agent, such as air, carbon dioxide gas, free acids, or dissolved salts, such as magnesium chloride, which have a corrosive action upon iron and steel. The purest waters, such as rain-water and melted snow, generally contain dissolved gases, and sometimes sulphuric acid, obtained from the atmosphere in localities where great quantities of coal containing sulphur are burned, and these waters if used in boilers, the inner surfaces of which are clean and unprotected by a coating of scale, may cause pitting of the plates, or more or less general corrosion. The corrosion produced by such waters may usually be prevented by occasionally adding a little milk of lime to the water, just enough to cause a very thin coating of scale upon the plates. Pitting, which is due to dissolved gases, occurs when the boiler is merely warm to a much greater extent than when it is hot and in service. When a boiler is to be kept out of service for any length of time, particular care should be taken to insure that the water in it, if it has any corrosive tendency, should be neutralized by the addition of milk of lime.

Distilled water, such as that obtained from the returns of steam-heating systems, in which exhaust steam is used, and from surface-condensers, is also apt to be corrosive, due to the accumulation in it of fatty acids generated by the decomposition of the vegetable or animal oils, which are often used in "compounded" lubricating oils. When such water is used, the oil should be removed from it as much as possible before it enters the boiler, and the acid should be neutralized by the addition of a very small amount of alkali.

A much more important and more dangerous cause of corrosion than those above mentioned is the use of water containing free sulphuric acid, or acid salts, such as is often found in streams in the vicinity of coal-mines, or in streams polluted by the discharge into them of refuse from dye-works, chemical factories, and other manufacturing establishments. When such water is the only kind available for a steam-boiler, then it is necessary, in order to prevent its corroding the boiler, to neutralize the acid by adding an alkali, such as carbonate of soda, to the water. The presence of acid in the water in a boiler may be tested by drawing a small sample from the bottom gage-cock and inserting into it a piece of blue litmus paper, which

may be obtained at a drug-store. If there is free acid in the water the blue color in the paper will be changed to red. By adding alkali to the acid water, drop by drop, and stirring thoroughly, the red color will be changed back to blue as soon as the alkali becomes in excess. In order to determine the quantity of carbonate of soda which should be added to acid feed-water to neutralize the acid, a pint of it may be taken from the supply pipe (not from the boiler, as there the acid may have become concentrated by evaporation), and a strip of blue litmus paper be immersed in it for half its length, and allowed to remain a minute or two. The blue color of the wetted portion will change to purple if the water is very slightly acid, and to red if it is more strongly acid. Then add carefully a solution of carbonate of soda, say 1 ounce dissolved in a quart of water, until the purple color begins to change to blue or the red to purple. Measuring the quantity of the solution which has been required to effect the slightest change of color gives us a means of estimating the amount of carbonate of soda which is needed to neutralize the acid in a given amount of acid feed-water, and make it silghtly alkaline. When the water is exactly neutral, it will not change the color of either red or blue litmus paper. When the proportion of alkaline water of a known strength required to neutralize the acid in the feed-water has thus been determined, it may be added to the water either in the supply-tank, or pipe, in the feed-water heater, or in the boiler, as may be most convenient. When a feed-water heater is used the alkali should be added either in it or in the supply before the water reaches the heater, for if not added until after the water passes the heater, the acid will corrode the heater. It is better always to add the alkali in the supply-tank, for the acid is apt to corrode the pump and the pipes, as well as the heater and the boiler.

When the feed-water contains simply free acid without any important amount of scale-formng material, such as lime or magnesia, the treatment by carbonate of soda is usually all that is necessary, but if lime or magnesia or both are present, the treatment becomes a more complicated matter, and it is then most desirable to call in the services of a chemist who is expert in the treatment of bad feed-waters and take his advice as to method of purification to be adopted. In such cases it will usually be necessary to use large settling-tanks, adding caustic lime or carbonate of soda, or both, for precipitating and settling out the hydrate or carbonate of lime formed by the chemical reaction, or else to use a live-steam feed-water heater, after

neutralizing the water with carbonate or caustic soda, in which the scale-forming materials will be deposited. It is necessary always to avoid using an excess of soda or other alkali, for such excess is apt to cause foaming. As the quality of the water is apt to vary from time to time, the impurities diminishing in rainy seasons and increasing in times of drought, it is advisable to have tests of the water made frequently, and to vary the amount of reagents used in accordance with the results of these tests. Organic matter, contained in sewage or in water from swamps, peat-bogs, etc., is sometimes a cause of corrosion, which may be prevented by proper chemical treatment.

Kerosene oil, which is sometimes used as a scale preventive, is said to be sometimes a cause of corrosion, due to the fact that the oil may contain traces of the sulphuric acid which was used in its purification. Water containing chloride of magnesium is apt to be corrosive, since this salt decomposes at high temperatures, liberating free acid. The acid may be neutralized by carbonate of soda.

Weakening of the plates by corrosion is one of the greatest dangers to which boilers are liable, and it should be guarded against by frequent and thorough inspection of the interior by a competent inspector, and whenever it is found no expense should be spared to prevent its continuance. If the corrosion is trifling in amount, some simple remedy may usually be found, such as rendering the water slightly alkaline by lime-water or carbonate of soda.

Sometimes a remedy is found in hanging zinc plates in the water in the boiler, suspending them by wires or rods which are soldered to the upper part of the shell, so as to make an electric connection, the zinc, the steel plates of the boiler, and the corrosive water thus forming a galvanic battery, the zinc being eaten away and the iron being thus protected.

The following note on the use of zinc is taken from a report by the Committee on Boilers of the Institution of Mechanical Engineers (1884):

Of all the preservative methods adopted in the British service, the use of zinc properly distributed and fixed has been found the most effectual in saving the iron and steel surfaces from corrosion, and also in neutralizing by its own deterioration the hurtful influences met with in water as ordinarily supplied to boilers. The zinc slabs now used in the navy boilers are 12 in. long, 6 in. wide, and ½ in. thick; this size being found convenient for general application. The amount of zinc used in new boilers at present is one slab of the above size for every 20 I.H.P., or about one square foot of zinc-surface to two square

feet of grate-surface. Rolled zinc is found the most suitable for the purpose. To make the zinc properly efficient as a protector especial care must be taken to insure perfect metallic contact between the slabs and the stays or plates to which they are attached. The slabs should be placed in such positions that all the surfaces in the boiler shall be protected. Each slab should be periodically examined to see that its connection remains perfect, and to renew any that may have decayed; this examination is usually made at intervals not exceeding three months. Under ordinary circumstances of working these zinc slabs may be expected to last in fit condition from sixty to ninety days immersed in hot sea-water; but in new boilers they at first decay more rapidly. The slabs are generally secured by means of iron straps 2 in. wide and ⅜ in. thick, and long enough to reach the nearest stay, to which the strap is firmly attached by screw-bolts.

On the same subject *The Locomotive* says:

Zinc is often used in boilers to prevent the corrosive action of water on the metal. The action appears to be an electrical one, the iron being one pole of the battery and the zinc being the other. The hydrogen goes to the iron shell and escapes as a gas into the steam. The oxygen goes to the zinc.

On account of this action it is generally believed that zinc will always prevent corrosion, and that it cannot be harmful to the boler or tank. Some experiences go to disprove this belief, and in numerous cases zinc has not only been of no use, but has even been harmful. In one case a tubular boiler had been troubled with a deposit of scale consisting chiefly of organic matter and lime, and zinc was tried as a preventive. The beneficial action of the zinc was so obvious that its continued use was advised, with frequent opening of the boiler and cleaning out of detached scale until all the old scale should be removed and the boiler become clean. Eight or ten months later the water-supply was changed, it being now obtained from another stream supposed to be free from lime and to contain only organic matter. Two or three months after its introduction the tubes and shell were found to be coated with an obstinate adhesive scale, composed of zinc oxide and the organic matter or sediment of the water used. The deposit had become so heavy in places as to cause overheating and bulging of the plates over the fire.

H. A. Wyckoff, *Power*, November 12, 1912, writes as follows concerning the placing of zinc slabs in boilers to prevent pitting:

"I have found the best way, for convenience in cleaning out and making renewals, to be to construct a pan of ⅛-in. iron, any size to suit the conditions and shape of the braces, and suspend it from the braces so it will clear the top row of tubes by 2 or 3 inches. Turn up the edges of the pan not less than 2 inches and drill a number of small holes in the bottom. In a few weeks, depending on the aciditv of the water, the zinc will have pulverized and become like gravel—depending on the amount of dross in it.

"If the back end of tubes and shell show most pitting, hang the basket or pan at that end; if the front end is most affected, put it there."

In the same issue of *Power,* J. C. Hawkins describes as follows the method of using zinc in the boilers of U. S. battleships:

"An iron box is made of ¼-in. material 12 in. wide by 40 in. long, and 13 in. deep. Large holes are cut in the sides and bottom, and the top is left open. This is suspended from the shell of the steam drum and comes just below the water line. In this box are placed 18 slabs of zinc, each 12x12x½ in.—set six in a row, or a total of about 333 pounds in each boiler. These slabs are set on edge in the box with holes drilled in them and through the box, through which ½-in. rods are run with large nuts or washers between the slabs to hold them in place and about 1¼ inches apart. The rods have a split pin through the end to keep them in place. This arrangement exposes the greatest surface of zinc to the action of the water which passes through the holes in the box and around the plates of zinc. The action of the water on these slabs causes them to waste away, but when they are taken out there is a coating of scale on them which often entirely fills up the space between the slabs. This scale is easily cracked off when dry, and leaves the slabs about one-quarter or one-half their original thickness. These slabs, if too thin, are not used again.

"The water used in the boilers of these ships, although coming from the evaporators, is more or less salty and contains chemicals that cause galvanic action and pitting. When zinc is used the galvanic action takes place on the zinc instead of on the boiler, as zinc has a stronger attraction for the acids than the iron.

"In one battleship there are 16 water-tube boilers with a total of 29,000 H.P., or 1812 H.P. each. Each boiler has one box of these zinc plates. I should judge that 10 to 15 lb. of zinc slabs suspended in the drum just below the water line, or about 7 lb. per 100 boiler-H.P. would be sufficient for a stationary boiler."

Painting Boiler Shells to Prevent Pitting.—Zinc paint is reported to have given satisfactory results as a preventive of pitting, and a correspondent of *Power* writes that boilers that were corroding and pitting rapidly were prevented from further deterioration by first cleaning the plates thoroughly with a scraper and a wire brush, then painting them with a paint made of linseed oil and Portland cement, and after this had dried, with a second coat made with one part graphite and three parts cement. In three years after this treatment the pitting had not extended.

If the corrosion is serious it may be necessary either to change the feed-water or, if this is not practicable, to treat it with chemicals in tanks and filter it before allowing it to enter the boiler.

Grooving or channelling is a kind of local corrosion, usually found adjacent to the seams of the shell of a boiler. It is commonly due to a combination of slightly acidulated water and of strains in the boiler-shell due to expansion and contraction, which cracks the scale off the shell and exposes the clean metal. It is an extremely dangerous form of corrosion, and calls for an immediate remedy.

Fig. 237 shows an example of pitting, and Fig. 238 one of grooving.

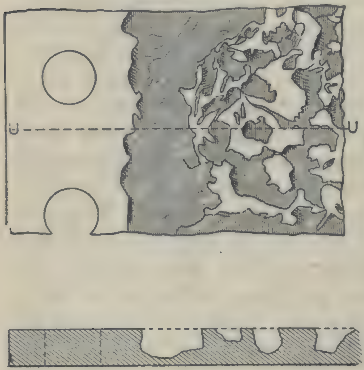

FIG. 237.—A PLATE BADLY FITTED.

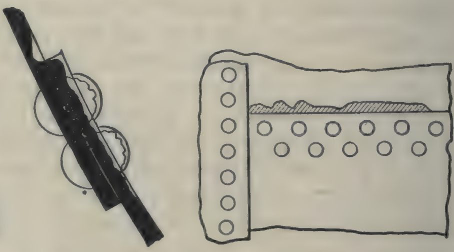

FIG. 238.—GROOVING AT A LAP JOINT.

Incrustation or Scale.—The formation of scale is the most common of all boiler troubles. It is due to the presence in the feed-water of various substances, some of which, such as clay and finely divided vegetable or organic matter, are carried in suspension and others are carried in solution. Of the substances that are held in solution, some, such as carbonate of lime, are precipitated by heating to a temperature of 212°; others, such as sulphate of lime, are precipitated to some extent at higher temperatures. Still others, such as common salt, cannot be precipitated at all, but remain in solution until enough water is evaporated away to cause the solution to become saturated; that is, holding the greatest possible quantity of salt in solution, when the salt begins to crystallize, and it will then rapidly form a coating on the boiler-surfaces.

When the scale-forming material is, like common salt, incapable of being precipitated by heating, but capable of forming solid masses by concentration and crystallization, it may to some extent be prevented from forming scale by frequent blowing off, so as to keep the strength of the brine below the saturation-point. This was the old practice with marine boilers using sea-water, before surface-condensers and feed-water evaporators came into use. It is still the only method

by which salt water can be used in a steam-boiler. Sea-water, however, contains sulphate of lime and other impurities which will be precipitated and make scale at high temperatures.

When the scale-forming material is carried in suspension in the water, whether in the original cold feed-water, as in the case of clay in muddy water, or in fine particles precipitated by heat in the feed-water heater or in the boiler, or by the addition of chemicals, the evaporation of the water in the boiler will cause this material to accumulate, and it will give rise to trouble unless it is removed. It is apt to take any one of three forms; sometimes all three of them may be formed from the same water. The first is scum, which floats on top of the water, and may be removed by a scum-collector and a surface blow-off. The second is soft mud, which, while it is in a very soft, almost liquid condition, may be blown out through the blow-off valve, or when the boiler is laid off for cleaning may be washed out with a jet of water from a hose. The third is solid scale, ranging from a soft chalk which may easily be broken by the fingers, to hard cement or a porcelain-like substance which it is difficult to break or cut by a hammer and chisel.

The scum, which at first floats on the surface, will, if allowed to accumulate, sink and be deposited on the tubes or shell of the boiler, and will become either mud or scale. The mud, which may be washed out of the boiler, may also become cemented by the other substances precipitated from the water, or may be baked on the shell. Scale attaches itself to all the metal surfaces of the boiler, including tubes, rivet-heads, braces, etc., as well as to the shell.

The effect of scale in a boiler ordinarily is to reduce both its steam-generating capacity and its economy, since it is not a good conductor of heat, and therefore diminishes the transmission of heat through the plates. It is also often highly dangerous, whenever it accumulates to such an extent, at a part of the shell which is exposed to flame, or to very hot gases, that the plates become overheated and weakened. A thin scale may form on the tubes, be cracked off by their expansion and contraction, or detached by the action of some "boiler compound," and may then be carried by the circulation and deposited in a thick mass on the shell over the fire. This may cause a "bagged" plate, or a crack and an explosion. If the scale is dense and hard, so as to be practically waterproof, a thin coating of it may be an effective non-conductor, and it may be a source of great danger as well as of loss of economy. If, however, it is porous, as many scales are, it will

allow water to pass through it to the metal surfaces of the boiler, and the decreased transmission of heat will be very slight.

Effect of Scale on Boiler Efficiency.—The following statement or a similar one has been published and republished for forty years or more by makers of "boiler compounds," feed-water heaters and water-purifying apparatus, but the author has not been able to trace it to its original source:*

"It has been estimated that scale $\frac{1}{50}$ of an inch thick requires the burning of 5 per cent of additional fuel; scale $\frac{1}{25}$ of an inch thick requires 10 per cent more fuel; $\frac{1}{16}$ of an inch of scale requires 15 per cent additional fuel; $\frac{1}{8}$ of an inch, 30 per cent, and $\frac{1}{4}$ of an inch, 66 per cent."

The absurdity of the last statement may be shown by a simple calculation. Suppose a clean boiler is giving 75 per cent efficiency with a furnace temperature of 2400° F. above the atmospheric temperature. Neglecting the radiation and assuming a constant specific heat for the gases, the temperature of the chimney gases will be 600°. A certain amount of fuel and air supply will furnish 100 lbs. of gas. In the boiler with $\frac{1}{4}$-in. scale 66 per cent more fuel will make 66 lbs. more gas. As the extra fuel does no work in evaporating water, its heat must all go into the chimney gas. We have then in the chimney gases

100 lbs. at 600° F., product	60,000
66 lbs. at 2400° F., product	158,400
	218,400

which divided by 166 gives 1370° above atmosphere as the temperature of the chimney gas, or more than enough to make the flue connection and damper red hot. (Makers of boiler compounds, etc., please copy.)

Another writer says: "Scale of $\frac{1}{16}$ inch thickness will reduce boiler efficiency $\frac{1}{8}$, and the reduction of efficiency increases as the square of the thickness of the scale."

This is still more absurd, for according to it if $\frac{1}{16}$-in. scale reduces the efficiency $\frac{1}{8}$, then $\frac{3}{16}$-in. will reduce it $\frac{9}{8}$, or to below zero.

* A committee of the Am. Ry. Mast. Mechs. Assn. in 1872 quoted from a paper by Dr. Jos. G. Rodgers before the Am. Assn. for Adv. of Science (date not stated): "It has been demonstrated [how and by whom not stated] that a scale $\frac{1}{16}$ in. thick requires the expenditure of 15 per cent more fuel. As the scale thickens the ratio increases; thus when it is $\frac{1}{4}$ in. thick, 60 per cent more is required." Mr. John Graham in the "Memoirs of the Literary and Philosophical Society" of Manchester, 1860, described some experiments made by him and states that "a scale of sulphate of lime $\frac{1}{16}$ in. thick reduced the efficiency 14.7 per cent."

From a series of tests of locomotive tubes covered with different thicknesses of scale up to $\frac{1}{8}$-in. Prof. E. C. Schmidt (Bull. No. 11 Univ. of Ill. Experiment Station, 1907), draws the following conclusions:

1. Considering scale of ordinary thickness, say varying up to $\frac{1}{8}$-inch, the loss in heat transmission due to scale may vary in individual cases from insignificant amounts to as much as 10 or 12 per cent.

2. The loss increases somewhat with the thickness of the scale.

3. The mechanical structure of the scale is of as much or more importance than the thickness in producing this loss.

4. Chemical composition, except in so far as it affects the structure of the scale, has no direct influence on its heat-transmitting qualities.

In 1896 the author made a test of a water-tube boiler at Aurora, Ill., which had a coating of scale about $\frac{1}{4}$-in. thick throughout its whole heating surface, and obtained practically the same evaporation as in another test, a few days later, after the boiler had been cleaned. This is only one case, but the result is not unreasonable when it is known that the scale was very soft and porous, and was easily removed from the tubes by scraping.

Prof. R. C. Carpenter (*Am. Electrician,* August, 1900), says: "So far as I am able to determine by tests, a lime scale, even of great thickness, has no appreciable effect on the efficiency of a boiler, as in a test which was conducted by myself the results were practically as good when the boiler was thickly covered with lime scale as when perfectly clean. . . . Observations and experiments have shown that any scale porous to water has little or no detrimental effect on economy of the boiler. There is, I think, good philosophy for this statement; the heating capacity is affected principally by the rapidity with which the heated gases will surrender heat, as the water and the metal have capacities for absorbing heat more than a hundred times faster than the gas will surrender heat.

A thin film of grease, being impermeable to water, keeps the latter from contact with the metal and generally produces disastrous results. It is much more harmful than a very thick scale of carbonate of lime.

Danger from Scale, Dirt and Oil in Marine Boilers.*—The tubes are likely to become impaired by the presence within them of air, oil, dirt or scale. Scale is the evil that should be most dreaded, since if care is exercised the introduction of dirt or oil should be prevented. Since the water tender can give a dose of salt feed at any time, and as he will certainly give such a supply rather than run the risk of getting low water, some salt water undoubtedly goes into the boiler every day. It also may come from leaky valves. If from any cause

* From a paper by H. C. Dinger, in Jour. Am. Soc. Naval Engrs., Feb., 1903.

considerable scale is allowed to deposit, the tubes are liable to burn out. From salt alone no serious results need be apprehended, but no salt water ever enters without carrying some scale.

A deposit of considerable thickness of dirt will produce conditions that will result in the burning out of the tubes. Skill in management and judgment in blowing down will prevent muddy sediment from collecting. If dirty water is used, it is imperative to blow down regularly, so that dangerous accumulations of sediment cannot form.

The strictest precaution should be taken to prevent as little oil as possible from reaching the tubes. As it is imposible to keep the tubes entirely clear of oil, since the oilers will pour oil into the auxiliaries, even if they are sparing at the main engines, some means must be taken to saponify or to dissolve the oil in solution or deposited on the inside of the tubes—then the oil products can be blown overboard. This can be done by the use of caustic soda, the amount required being determined by special conditions.

It is also advisable occasionally to boil out the tubes with a strong solution of soda. Another way of getting rid of oil is to introduce about ten pounds of soda into the boiler, then get up steam quickly. After allowing the alkaline water in the boiler to stand for a time and thus neutralizing the acid and dissolving or saponifying the oil, the surface blow valve should be slightly used, and then the boiler should be emptied by means of the bottom blow valve. Where fresh water is scarce there will naturally be a disinclination to resort to this remedy.

Another way is to pump the boiler about one-third full of fresh water and then enter the soda. Admit a little steam through the auxiliary stop valve to heat the contained water. Then circulate the water through the boiler by means of an auxiliary pump, using any available auxiliary to effect this object.

It is regular and uniform cleaning, and not intermittent attention, which will insure efficiency and safety. The use of zincs is also advisable, the number and location of the baskets or slabs being dependent upon experiment, experience and character of the water.

Methods for Prevention or Removal of Scale.—The methods of treatment adopted for the removal or prevention of scale are numerous. The most common, perhaps, is to allow it to accumulate in the boiler until it is thought to be thick enough to be a source of danger, or of loss of economy, and then to remove it by mechani-

cal means. This may be a good enough method in some cases, especially when the water is not very bad, so that it requires several months for a coating of objectionable thickness to form, when the scale is of such a nature that it does not detach itself and accumulate in thick patches over the fire, and when the boiler is of such a construction that it is possible to clean it thoroughly, such as a water-tube boiler with straight tubes.

Another method, commonly used, is to introduce periodically into the boiler a solution of some chemical, such as caustic soda, tannate, carbonate and phosphate of soda, etc., which will cause a change in the chemical composition of the scale-forming material, making a precipitate which may be easily removed and a soluble material which may be kept below the point of concentration by occasional blowing-off.

These chemicals form the base of many of the "boiler compounds," some of which may cure the disease, while many will not, although they are sold at a very high price compared with the market value of the chemicals. In relation to these compounds Mr. Albert A. Cary says:

Never use any boiler compound unless you know positively just what it is composed of, and how it will affect the impurities in your boiler and the boiler itself. In the treatment of boiler-waters, always start with a careful analysis of the water, made by a competent chemist who has experience in this line. Next, if you are thinking of using any chemical that has been offered for treatment of your boiler-water, let your chemist analyze it. If you are dealing with straightforward people, they will generally tell you the exact composition of their material, which your chemist can verify easily, after which he will be prepared to advise properly. (*Engineering Magazine*, June, 1897.)

In 1885 a report made by the Bavarian Steam-boiler Inspection Association gave a list of twenty-seven boiler compounds which had been analyzed. It commented on them as follows:

All secret compounds for removing boiler-scale should be avoided. Such secret preparations are either nonsensical or fraudulent, or contain either one of the two substances (soda or lime) recommended by the Association for removing scale, generally soda, which is colored to conceal its presence, and sometimes adulterated with useless or even injurious matter. These additions, as well as giving the compound some strange, fanciful name, are meant simply to deceive the boiler-owner and conceal from him the fact that he is buying colored soda, or similar substances, for which he is paying an exorbitant price.

Besides the methods of removing the scale after it has encrusted the boiler, and preventing its formation by means of chemicals introduced into the boiler and frequent blowing-off, there are many ways of treating water to remove its scale-forming material before allowing it to enter the boiler. A common method, and for some kinds of water one of the best, is to heat the water in an open feed-water heater. If the scale-forming material is simply bicarbonate of lime, that is, mono-carbonate held in solution by carbon dioxide gas dissolved in the water, it may be almost entirely precipitated by continued heating to drive off the carbon dioxide gas. The insoluble carbonate thus precipitated will attach itself to the plates of the heater, which therefore needs to be cleaned frequently. Even sulphate of lime can be precipitated to a considerable extent by heating it to about 300° in a live-steam feed-water heater, such as the Hoppes.

When the water is very bad, the feed-water heaters may prove insufficient to purify it, and then recourse must be had to treatment of the water by chemicals in tanks, and subsequent slow settling or filtration to remove the sediment formed. Hydrate or milk of lime, carbonate of soda and caustic soda are the chemicals used. This method requires a somewhat expensive equipment, and great care in its operation. It should not be undertaken without competent expert advice together with chemical analysis.

Keresone oil, and other refined petroleum oils, heavier than kerosene, are sometimes used with good effect in boilers to prevent the scale-forming materials attaching themselves to the boiler. These oils appear to rot the scale so that it may easily be removed. Crude oil should never be used, as it gives off inflammable vapors, and leaves a tarry residuum which may form with the scale a tough, greasy deposit on the plates over the fire and cause them to burn out.

A condensed summary of the various causes of incrustation, corrosion, etc., and their remedies, is given as follows in a paper by Messrs. A. E. Hunt and G. H. Clapp, in the Transactions of the American Institute of Mining Engineers, vol. xvii. p. 338, and credited to Prof. L. M. Norton, as follows:

CAUSES OF INCRUSTATION.

1. Deposition of suspended matter.

2. Deposition of salts from concentration.

3. Deposition of carbonates of lime and magnesia by boiling off carbonic acid, which holds them in solution.

4. Deposition of sulphates of lime, because sulphate of lime is soluble in cold water, less soluble in hot water, insoluble above 270° F.

5. Deposit of magnesia, because certain magnesium salts decompose at high temperatures.

6. Deposition of lime-soap, iron-soap, etc., formed by saponification of grease.

METHODS OF PREVENTING INCRUSTATION.

1. Filtration.
2. Blowing-off.
3. Use of internal collecting apparatus, or devices for directing the circulation.
4. Heating feed-water.
5. Chemical or other treatment of water in boiler.
6. Introduction of zinc in boiler.
7. Chemical treatment of water outside of boiler.

Troublesome Substance.	Trouble.	Remedy or Palliation.*
Sediment, mud, clay, etc.	Incrustation.	Filtration; blowing-off.
Readily soluble salts.	Incrustation.	Blowing-off.
Bicarbonates of lime, magnesia and iron.	Incrustation.	Heating feed; addition of caustic soda, lime, etc.
Sulphate of lime.	Incrustation.	Addition of carbonate of soda, barium hydrate, etc.
Chloride of magnesium	Corrosion	Addition of carbonate of soda, etc.
Carbonate of soda in large amounts.	Priming.	Addition of barium chloride, etc.
Acid (in mine-water).	Corrosion.	Alkali.
Dissolved carbonic acid and oxygen.	Corrosion.	Feed milk of lime to the boiler, to form a thin internal coating.
Grease (from condensed water).	Corrosion or incrustation.	Different cases require different remedies. Consult a specialist on the subject.
Organic matter (sewage).	Priming. corrosion or incrustation	

* The author has taken the liberty of altering this table somewhat from the original.

The subject of the scientific treatment of bad feed-waters is a large and complex one, and the practical application of the proper methods is rather recent in this country. Those who are further interested in this matter should consult the paper of Messrs. Hunt and Clapp, from which the above summary is taken, and also Mr. Albert A. Cary's paper on Corrosion and Scale from Feed-waters, in the *Engineering Magazine* for March, April, May, and June, 1897. Accounts of the use of petroleum for preventing incrustation will be

found in Trans. Am. Soc. M. E., vols. ix. and xi., a statement of the method of purification used by the Solvay Process Company, Syracuse, N. Y., in vol. xiii. p. 255, and a description of the method used on the line of the Southern Pacific Railway in a paper by Mr. Howard Stillman, in vol. xix. p. 415.

Boiler Compounds.—W. M. Booth (*Eng. News,* July 27, 1905), gives the analyses of several boiler compounds which he has examined. One, a white powder, was composed of soda ash with a little free tannic acid. Another, a black liquid, contained mainly caustic soda in excess, logwood, tannin, sugar, sulphate of soda and a small quantity of gum. Its use was prohibited. A third contained catechu, caustic soda and tan liquor. These liquids were sold for about 50 cts. per gallon and cost less than 6 cts, to make. Mr. Booth says:

"We have two materials the use of which in boilers is not prohibited through action upon the metal itself or on account of price. If prescribed as per analysis, in slight excess, there should be no injurious results through their use. There is a great deal of fraud in connection with boiler compounds generally. A better class of vendors advertise to build a special compound for a special water. The less scientific members of the boiler compound guild carefully consign each sample of water to the sewer and send the regular goods. Others have a stock analysis which is sent to customers of a given locality whether it contains iron, lime, or magnesium sulphates or carbonates.

"For plants of from 75 to 150 H.P., 24-hour settling tanks will answer the purpose of a softening system. Two tanks, each capable of holding a day's supply and furnished above with lime and soda tanks in common, and provided with sludge valves below, may be used for this purpose. Paddles in each tank capable of thoroughly stirring the contents may be actuated from above. Such a system has an advantage over a continuous system, in that the exact amount of chemical solutions required for softening the particular water in the tank can be applied. For some variations of such a system, several companies have secured patents and are doing a large business. The fundamental principles are not patentable, and have been used for many years.

The Use of Boiler Compounds.* To the majority of steam-users, anything that is put into a boiler to lessen troubles due to the forma-

* From an article by Albert A. Cary in *American Machinist,* Dec. 7, 1899.

tion of scale, is a "boiler compound," and the fact that these various so-called compounds act differently in their endeavor to accomplish their purpose is not generally understood. Such nostrums may be divided into three classes:

First—Those attacking the scale-producing material chemically. These act as reagents and combine with the matter precipitated from the feed-water, forming a third substance different from either the original precipitated solids or the "reagent," the theory being that the new substance will not form into a hard, resisting scale, and therefore can be more easily removed by blowing-off or by the cleaning tools used after the boiler is opened.

Second—Those acting mechanically upon the precipitated crystals of scale-making matter soon after they are formed. Such "compounds" are of a glutinous, starchy or oily nature, and become attached to the surface of the newly formed crystals (precipitated from the water) surrounding them, as the skin does an orange; and when these crystals fall together they are thus robbed of their cement-like action, which frequently occurs when they are allowed to come in immediate contact.

Third—Those acting both mechanically (as just described) and also as a solvent, the latter action partially dissolving scale already formed, and by this "rotting" effect (as it is often called) preparing the scale for easy removal.

The "compounds" under the first division (which act chemically upon the scale-forming matter) also frequently accomplish this same rotting effect upon scale formed previous to their use. Still other divisions or sub-divisions might possibly be made, but the above will suffice for a good general idea of the subject.

Taking up our first division of this subject, we find that the principal ingredients used in such "compounds" are soda ash (or carbonate of soda) and tannin matters, while we sometimes find caustic soda, sal soda, acetic acid, and numerous other active agents which are generally less efficient in their action on the scale-forming matter and more harmful to the boiler and its fittings.

In order to disguise these very cheap chemicals and help the "compound" vender get big prices for his powder or liquid, whichever it may be, there are often added other substances which generally render the active agents less efficient, and they frequently fall unchanged to the bottom of the boiler with the scale, thus increasing the deposit and aggravating the trouble.

Such added substances include clay, chalk, sand, etc., and sometimes coloring matter is used to disguise the original chemicals, such as tobacco-juice, iron scraps, lampblack, spent tan, etc.

The principal scale-making impurities precipitated in boilers are carbonate of lime ($CaCO_3$), carbonate of magnesium ($MgCO_3$), sulphate of lime ($CaSO_4$) and sulphate of magnesium ($MgSO_4$), and although there are generally other precipitates, notice of these alone will be sufficient for the present consideration.

The chemical action taking place when some of the above-named active agents are used may be traced as follows:

Soda ash is a dry impure carbonate of soda, from which the pure alkali is afterwards made.

The carbonate of soda (Na_2CO_3) is used to act upon the sulphate of lime and magnesia, as shown in the following chemical formulæ:

(*a*)	Sulphate of Lime	and	Carbonate of Soda	form	Carbonate of Lime	and	Sulphate of Soda.
	$CaSO_4$	+	Na_2CO_3	=	$CaCO_3$	+	Na_2SO_4
(*b*)	Sulphate Magnesium	and	Carbonate of Soda	form	Carbonate Magnesia	and	Sulphate of Soda.
	$MgSO_4$	+	Na_2CO_3	=	$MgCO_3$	+	Na_2SO_4

Both the carbonate of lime and carbonate of magnesia are held in solution through the presence of carbonic acid gas dissolved in the water, which unites with them and changes the monocarbonates into bicarbonates (which are only known to exist in solution), as shown thus:

Carbonate of Lime	and	Carbonic Acid	and	Water	form	Bicarbonate of Lime	Generally Expressed
$CaOCO_3$	+	CO_2	+	H_2O	=	$CaO(CO_2)_2H_2O$	$= CaH_2(CO_3)_2$

In a similar manner the bicarbonate of magnesium is formed from the monocarbonate thus:

Carbonate of Magnesium	and	Carbonic Acid	and	Water	form	Bicarbonate of Magnesium,	Generally Expressed
$MgOCO_2$	+	CO_2	+	H_2O	=	$MgO(CO_2)_2H_2O$	$= MgH_2(CO_3)_2$

The monocarbonates (or single carbonates) of lime and magnesia are but slightly soluble in water, whereas the bicarbonates (or double carbonates) are very soluble in *cold* water, and this fact will account for the presence of the large quantities of lime and magnesia in boiler waters as carbonates.

When waters containing the bicarbonates are heated, the rise in temperature drives off the extra carbonic acid gas and leaves behind the practically insoluble monocarbonates, which are precipitated.

When a temperature of 180° Fahr. is reached, a considerable percentage of the bicarbonates is precipitated (as insoluble monocarbonates), and at 290° Fahr. (a temperature corresponding to 43 lbs. gage-pressure) the precipitation is nearly completed, after a thorough boiling.

Scale forming from the monocarbonate of lime is seldom very troublesome, if not allowed to accumulate in too large a quantity, nor allowed to remain in the boiler for a long time; while the precipitated monocarbonate of magnesia gives slightly more trouble, due to the fact that it seldom is found in scale as a monocarbonate. All

the contained carbonic acid (CO_2) is generally lost from the bicarbonate of magnesia ($MgO(CO_2)_2H_2O$) by the time it forms a crust, leaving behind the hydrate of magnesia ($MgO + H_2O = MgO_2H_2$), which acts as a cement and binds closely together (though not very strongly) whatever precipitated matter it may come in contact with.

This hydrate of magnesia is very fine and light when precipitated and requires a comparatively long time to settle.

The sulphates of lime and magnesia are very soluble, dissolving in water direct, without requiring the presence of carbonic acid or any other foreign agent.

The amount of sulphate of lime which can be dissolved in one United States gallon of water at different temperatures may be appreciated by examining the following table:

At 32° Fahr., 120 grains per gallon.
At 95° Fahr., 148 grains per gallon.
At 212° Fahr., 127 grains per gallon.
At 250° Fahr., 9 grains per gallon.
At from 260° to 302° Fahr., it is practically insoluble.

This latter temperature (302°) corresponds to 55 lbs. gage-pressure, and, therefore, when water is thoroughly boiled at this temperature, practically all of the sulphates will be precipitated. The crystals of sulphate of lime will be found to be long and needle-like, and also very heavy and possessing cement-like qualities, so they fall rapidly, and, mixing with the precipitated carbonates, they bind them together into a hard, resisting mass, difficult to remove with even hammer and chisel, if they form a considerable proportion of the scale.

It is here where the active agent in the compound is supposed to take effect, and by referring to the reaction given above—in the formulæ (*a*) and (*b*)—when the carbonate of soda is used, it will be seen that the sulphates of lime and magnesia are changed into carbonates, which are precipitated and form a scale varying from a more or less porous, friable crust to a "mush" or mud. The sulphate of soda, which is also formed by this reaction, is extremely soluble, remaining in solution at nearly all boiler temperatures and forming no scale, unless allowed to concentrate, and this is prevented by "blowing-off" occasionally.

The tannin matters, referred to above, are obtained from various vegetable sources containing tannic acid, such as certain kinds of sumach, gallnuts, catechu (or cutch) bark, etc. Tannin is generally combined with soda to form the tannate of soda for use with boiler waters to keep the deposit soft or in suspension. Its action is supposed to be as follows:

The tannate of soda decomposes the carbonates of lime and magnesia as they enter the boiler, and tannates of lime and magnesia are

precipitated in a light, flocculent, amorphous form and are long kept in suspension by the circulating currents of water, until they finally are deposited in a loose, mushy mass in that part of the boiler where the circulating currents are the weakest, or possibly in the mud-drum.

When the above reaction takes place the carbonate of soda is formed, which reacts with any sulphates that may be present,, as has already been described.

The use of tannic acid in the boiler cannot be recommended unreservedly, as it will attack the iron as well as the carbonates (although, of course, more slowly), and anything that will corrode the boiler itself certainly cannot be desirable. To test this, any one can obtain a few cents' worth of tannic acid from the druggist, and by dissolving the crystals in a glass of water and adding some iron filings a very fair quality of ink can be made, due to the action of this acid on the iron.

In practice, the reaction of caustic soda ($Na_2O_2H_2$) with the sulphates seems to be more active than when the carbonate of soda is used, the probable reaction being as shown thus:

Sulphate of Lime	and	Carbonic Acid	and	Caustic Soda	form	Caustic Lime	and	Carbonic Acid	and	Sulphate of Soda.
$CaSO_4$	+	CO_2	+	$2NaOH$	=	CaH_2O_2	+	CO_2	+	Na_2SO

The carbonic acid used in this formula results from the precipitation of the monocarbonates from the bicarbonates, as has been explained.

The secondary reaction from the result just arrived at is as follows:

Caustic Lime	and	Carbonic Acid	form	Carbonate of Lime	and	Water.
CaH_2O_2	+	CO_2	=	$CaOCO_2$	+	H_2O

The use of caustic soda may be considered less desirable than the use of the carbonate of soda for several reasons.

In the first place, if present in excess, it will cause violent foaming in the boiler, and with this foam often the light precipitated matter in the boiler will be carried along steam-pipes into valve-seats, gage-glasses, etc. It will also attack and cause corrosion of the brass fittings, and it is also dangerous to handle, owing to its caustic qualities, burning the flesh painfully wherever it comes in contact.

An excess of carbonate of soda may also cause foaming in the boiler, but not as violent as when caustic soda is used.

Sal ammoniac (ammonium chloride, NH_3HCl) is most undesirable for use in a boiler, due to the liberation of hydrochloric acid (HCl) following its introduction into the boiler. This acid leaves the boiler in a vaporous form, with the steam, corroding the boiler, piping, and nearly everything it comes in contact with.

There are other "compounds" falling under this classification, of

known chemical composition, which are more satisfactory than those named above, such as bisodium phosphate and trisodium phosphate, the latter being obtainable in both a hydrous and anhydrous state. The latter is less bulky and its reaction with the sulphate of lime is shown by the following formula:

2 Parts Trisodium Phosphate	and	3 Parts Sulphate of Lime	form	Phosphate of Lime	and	3 Parts Sulphate of Soda.
$2Na_3PO_4$	+	$3CaSO_4$	=	$Ca_3(PO_4)_2$	+	$3Na_2SO_4$

The phosphate of lime, after this reaction, falls, forming a slushy mud, making at the most a very weak crust, while the sulphate of soda remains in solution, as previously described.

The second division of compounds includes a class of materials which are gradually falling into disuse, due to their proved undesirability. They thicken and foul the water in the boiler and coat its surfaces with non-conducting material, and occasionally the precipitated scale-making matter, along with this class of compound, will obstruct the passage of heat through the boiler-plates, so as to cause bagging and burning.

In this class we find slippery elm, ground bones, horns and hoofs, potatoes, dextrine, and starch, animal fats and animal or vegetable table oils.

As rapidly as the scale-forming crystals are precipitated from the feed-water, they fall into this sticky fluid and become coated with its filth, and they finally fall to the place of deposit, where they remain in a mushy, separated state until the organic matter chances to be burned out, when they will form into a loose, friable scale.

A surface blow-off or skimming device is most essential to reduce the evil, when this class of compound is used, and the bottom blow-off cock should also be opened very frequently.

The principal substances used for the third class of compounds are petroleum and kerosene.

Petroleum oil has much more of the enveloping quality described under the last (or third) classification than the kerosene. Besides producing this effect on the scale-matter, both have an active rotting effect on the scale already formed, the kerosene in this case being superior to the petroleum.

Crude oil should never be used, but a carefully refined oil, which has been deprived of its tar or wax, should be selected for this purpose, as these cause the formation of a tough, impervious scale productive of bagged sheets and collapsed flues. Petroleum or kerosene should be fed to the boiler with the feed-water, drop by drop, through a sight-feed apparatus similar to those used to feed oil to the cylinders of engines. Under no consideration should large amounts of these oils be fed to a boiler at one time, as it must be remembered that the more volatile portion of the petroleum will be quickly distilled off in

the hot boiler, leaving the least efficient portion behind, while the more volatile kerosene will be vaporized very quickly, before it has time to thoroughly mix with the water.

Where hard scale has formed in a boiler, it is most effectually treated by giving it a coat of petroleum or kerosene, to partially dissolve or rot it. This may be applied with a brush or squirted on, but an easier method of application is to first fill the boiler with water above the line of scale-deposit and then pour the oil on the surface of this water and let the water gradually run out of the bottom of the boiler, thus leaving the oil behind clinging to the whole interior surface.*

As stated above, kerosene is the most effective in destroying the tenacity or coherence of this deposited scale, but this method of using either oil is not without attending danger, on account of the explosiveness of the vapor given off; so great care must be taken to have no lights in the vicinity of the boiler under such treatment, as men have been seriously injured by this lack of prudence.

The treatment of feed-waters inside of the boiler has been a practice of many years' standing, but in the light of recent progress is not to be commended. A boiler certainly has all that it can reasonably be expected to do when it is generating steam without being called upon to perform the functions of a chemical laboratory.

Mr. H. E. Smith, chemist of the Chicago, Milwaukee & St. Paul Ry. Co., in a letter to the author, June, 1902, writes as follows concerning the chemical action of soda-ash on the scale-forming substances in boiler waters:

Soda-ash acts on carbonates of lime and magnesia in boiler water in the following manner: The carbonates are held in solution by means of the carbonic acid gas also present, which probably forms bicarbonates of lime and magnesia. Any means which will expel or absorb this carbonic acid will cause the precipitation of the carbonates. One of these means is soda ash (carbonate of soda), which absorbs the gas with the formation of bicarbonate of soda. This method would not be practicable for softening cold water, but it serves in a boiler. The carbonates precipitated in this manner are in flocculent condition instead of semi-crystalline as when thrown down by heat. In practice it is desirable and sufficient to precipitate only a portion of the lime and magnesia in flocculent condition. As to equations, the following represent what occurs:

* An effective method of cleaning a boiler which has become heavily coated with hard sulphate of lime scale is to put in it a large quantity of caustic soda, say 50 lbs. for a large boiler, and boil it at atmospheric pressure, the safety valve being opened, for several hours. This converts the hard scale into a soft substance which may be removed by a scraper, followed by thorough washing with cold water.—W. K.

$$Ca(HCO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaHCO_3.$$
$$Mg(HCO_3)_2 + Na_2CO_3 = MgCO_3 + 2NaHCO_3.$$
$$(\text{free})\ CO_2 + Na_2CO_3 + H_2O = 2NaHCO_3.$$

Chemical equivalents: — 106 pounds of pure carbonate of soda—equal to about 109 pounds of commercial 58 degree soda-ash—are chemically equivalent to—*i. e.*, react exactly with—the following weights of the substances named: Calcium sulphate, 136 lbs.; magnesium sulphate, 120 lbs.; calcium carbonate, 100 lbs.; magnesium carbonate, 84 lbs.; calcium chloride, 111 lbs.; magnesium chloride, 95 lbs.

Such numbers are simply the molecular weights of the substances reduced to a common basis with regard to the valence of the component atoms.

Important work in this line should not be undertaken by an amateur. "Recipes" have a certain field of usefulness, but will not cover the whole subject. In water purification, as in a problem of mechanical engineering, methods and apparatus must be adapted to the conditions presented. Not only must the character of the raw water be considered, but also the conditions of purification and use.

Use of Kerosene to Remove Scale.—*The Locomotive,* July, 1898, comments on the use of kerosene for the removal of scale as follows:

We are of the opinion that the introduction of the oil daily, mixed with the feed water, is not the most effective method of using oil for the removal of scale that has already formed. We believe that much better results would be obtained as follows: The boiler is thoroughly dried out so as to remove all moisture from the scale. This is accomplished by opening the manhole and handholes, as soon as the boiler is blown down. When the boiler is cooled down sufficiently to be entered for examination and cleaning, the scale will then become dry. All sediment and loose fragments should then be brushed out, and kerosene oil sprayed over the plates and tubes, so as to saturate the scale thoroughly. The oil which accumulates in the bottom of the boiler will rise on the surface of the water when the boiler is filled, and be brought in contact with such parts of the tubes as may not be reached by the direct spray. Oil so applied will penetrate the scale and loosen it from the iron. The boiler should then be opened in a week or two, and all loose scale be removed. It is important to attend to this part of the operation, as otherwise there is great danger of the loose scale collecting upon the fire sheets, and causing them to burn or bulge. In tubular boilers it is often necessary to break down the scale lodged between the tubes. In water-tube boilers it is necessary to dry out as above described, uncap the tubes, and then, with a mop saturated in kerosene, brush through the tubes until the scale is saturated. If the boiler is allowed to stand for 24 hours, a scraper will remove considerable scale on which it would have no

effect previous to the saturation of the scale with kerosene. Opening and scraping the tubes after running the boiler for a week will remove much larger quantities. The thorough drying of the boilers is important, when this method is used, since oil will not penetrate wet scale. Open lights should not be used in or about the boiler when applying kerosene oil as above described.

Graphite as a Scale Preventive.—Finely ground flake graphite has been used with good effect in the removal of old scale from boilers and in preventing the adhesion of new scale to the plates. Its action is not chemical, but mechanical. The fine particles work their way into the minute cracks in the old scale and gradually penetrate between the scale and the metal. The manufacturers (Dixon Crucible Co.) say that if the scale is very hard and thick it may take three or four months for the graphite to loosen it, but once removed, scale can never adhere firmly to the metal as long as the graphite treatment is continued. The graphite becomes thoroughly intermixed with new scale as it forms, rendering it soft and crumbly.

The simplest way of feeding graphite into a boiler is to introduce it into the pump suction line by means of a funnel and valve such as are shown in Fig. 239. A pint of graphite is mixed in a pail of as are shown in Fig. 239. A pint of graphite is mixed in a pail of water and poured into the funnel while the valve is closed. When the valve is opened the mixture will be drawn into the pump. It is recommended that about one pint of graphite be fed into each boiler every twelve hours, with an extra one-third pint for every 100 H.P. above 250 H.P. When the old scale has been removed the amount should be reduced slightly.

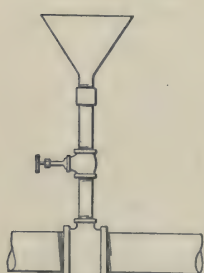

FIG. 239.—FUNNEL FOR GRAPHITE.

A correspondent of *Power*, November 12, 1912, writes that he used graphite with excellent effect as long as the boilers were using a certain feed-water, but when the water was changed the boilers scaled heavily and graphite only seemed to make the scale harder. "With graphite as with other compounds," he says, "what will give good results in one plant may be detrimental in another." Another correspondent says: "Graphite is not a substance that can be used carelessly. Unless proper care is taken to keep the blow-off pipe clear and means taken to remove the loosened scale its use is dangerous."

Water-softening Apparatus. (From the Report of the Committee on Water Service, of the Am. Railway Eng'g and Maintenance of Way Assn., *Eng. Rec.,* April 20, 1907.—Between three and four hours is necessary for reaction and precipitation. Water taken from running streams in winter should have at least four hours' time. At least three feet of the bottom of each settling tank should be reserved for the accumulation of the precipitates.

An article on "The Present Status of Water Softening," by G. C. Whipple, in *Cassier's Mag.,* Mar., 1907, illustrates several different forms of water-purifying apparatus. A classification of degrees of hardness corresponding to parts of carbonates and sulphates of lime and magnesia per million parts of water is given as follows: Very soft, 0 to 10 parts; soft, 10 to 20; slightly hard, 25 to 50; hard, 50 to 100; very hard, 100 to 200; excessively hard, 200 to 500; mineral water, 500 or more. The same article gives the following figures showing the quantity of chemicals required for the various constituents of hard water. For each part per million of the substances mentioned it is necessary to add the stated number of pounds of lime and soda per million gallons of water.

For Each Part per Million of	Pounds per Million Gallons.	
	Lime.	Soda.
Free CO_2	10.62	0
Free acid (calculated as H_2SO_4)	4.77	9.03
Alkalinity	4.67	0
Incrustants	0.00	8.85
Magnesium	19.48	0

The above figures do not take into account any impurities in the chemicals. These have to be considered in actual operation.

An illustrated description of a water-purifying plant on the Chicago & Northwestern Ry. by G. M. Davidson is found in *Eng. News,* April 2, 1903. Two precipitation tanks are used, each 30 ft. diam., 16 ft. high, or 70,000 gallons each. As some water is left with the sludge in the bottom after each emptying, their net capacity is about 60,000 gallons each. The time required for filling, precipitating, settling and transferring the clear water to supply tanks is 12 hours. Once a month the sludge is removed, and it is found to make a good whitewash. Lime and soda-ash, in predetermined quantity, as found by analysis of the water, are used as precipitants. The table on top of p. 536 shows the effect of treatment of well water at Council Bluffs, Iowa.

The minimum amount of scaling matter which will justify treatment cannot be stated in terms of analysis alone, but should be stated in terms of pounds incrusting matter held in solution in a day's supply. Besides the scale-forming solids, nearly all water contains

	Before Treatment.	After Treatment.
Total solid matter, grains per gallon	53.67	31.35
Carbonates of lime and magnesia	25.57	3.14
Sulphates of lime and magnesia	19.55	
Silica and oxides of iron and aluminum	1.76	0.40
Total incrusting solids	46.88	3.54
Alkali chlorides	1.21	1.27
Alkali sulphates	5.58	26.32
Total non-incrusting solids	6.79	27.81
Pounds scale-forming matter in 1000 gals	6.69	0.51

more or less free carbonic acid. Sulphuric acid is also found, particularly in streams adjacent to coal mines. Serious trouble from corrosion will result from a small amount of this acid. In treating waters, the acids can be neutralized, and the incrusting matter can be reduced to at least 5 grains per gallon in most cases.

QUANTITY OF PURE REAGENTS REQUIRED TO REMOVE ONE POUND OF INCRUSTING OR CORROSIVE MATTER FROM THE WATER.

Incrusting or Corrosive Substance Held in Solution.	Amount of Reagent. (Pure.)	Foaming Matter. Increased.
Sulphuric acid	0.57 lb. lime plus 1.08 lbs. soda ash	1.45 lbs.
Free carbonic acid	1.27 lbs. lime	None
Calcium carbonate	0.56 lb. lime	None
Calcium sulphate	0.78 lb. soda ash	1.04 lbs.
Calcium chloride	0.96 lb. soda ash	1.05 lbs.
Calcium nitrate	0.65 lb. soda ash	1.04 lbs.
Magnesium carbonate	1.33 lbs. lime	None
Magnesium sulphate	0.47 lb. lime plus 0.88 lb. soda ash	1.18 lbs.
Magnesium chloride	0.59 lb. lime plus 1.11 lbs. soda ash	1.22 lbs.
Magnesium nitrate	0.38 lb. lime plus 0.72 lb. soda ash	1.15 lbs.
Calcium carbonate	1.71 lbs. barium hydrate	None
Magnesium carbonate	4.05 lbs. barium hydrate	None
Magnesium sulphate	1.42 lbs. barium hydrate	None
Calcium sulphate*	1.26 lbs. barium hydrate	None

* In precipitating the calcium sulphate there would also be precipitated 0.74 lb. of calcium carbonate or 0.31 lb. of magnesium carbonate, the 1.26 lbs. of barium hydrate performing the work of 0.41 lb. of lime and 0.78 lb. of soda ash, or for reacting on either magnesium or calcium sulphate, 1 lb. of barium hydrate performs the work of 0.33 lb. of lime plus 0.62 lb. of soda ash, and the lime treatment can be correspondingly reduced.

Barium hydrate has no advantage over lime as a reagent to precipitate the carbonates of lime and magnesia and should not be considered except in connection with the treating of water containing calcium sulphate.

Method of Testing Boiler Waters.—A. J. Boardman, in *Power,* March 3, 1909, describes the method of testing water before and after

softening by means of soda-ash and lime, used in an 8400 H.P. boiler plant in Indianapolis. The analysis of the river water showed a total of 25.3 grains of scale forming and suspended matter per U. S. gallon, the incrusting solids being 15.69 grains per gallon or 2.24 pounds per 1000 gallons. Before the treatment was adopted different boiler compounds had been used, at an average cost of $270 per month, with very little decrease in the amount of scale, and from 15 to 64 boiler tubes were burned out in a month. With the new treatment, costing $104 per month, the maximum number of tubes replaced in a month was only two. An abstract of Mr. Boardman's paper follows:

It was decided to treat the water by using soda ash and lime to throw down the scale-forming matter, and to check this treatment with feed-water analysis.

The expenditure for a testing outfit was not over $10. The apparatus consisted of two 50-cc. burettes, one square pint bottle with rubber cork, one pint standard N/50 HCl solution, one pint standard soap solution, three 500-cc. beakers, one funnel, 100 filter papers No. 2, one 100-cc. phenolphthalein indicator, one 100-cc. methyl orange indicator, one 100-cc. graduated test tube, 10 ounces barium chloride, stirring rod, burette support, stand, etc. It is necessary to have HCl exactly correct. Normal HCl is 98.7 per cent hydrochloric acid.

Hard water may be defined as water containing in solution mineral compounds that curdle or precipitate soap; generally the salts of lime, magnesia, iron, etc. In the United States hardness is generally stated as parts of calcium carbonate per million, i. e., the number of parts by weight of $CaCo_3$ that would have to be added to a million parts by weight of water to produce the specified degree of hardness. To convert grains per gallon to parts per million multiply by 17.14. The standard soap solution is obtained by dissolving pure castile soap in alcohol.

Total Hardness.—In testing for total hardness in river water, 25 cc. of the water is diluted with 75 cc. of distilled water. This is titrated with the standard soap solution in a square pint bottle provided with a rubber stopper. One cc. of soap solution is added at a time until there is some evidence of a permanent lather. Then add ½ cc. and decrease to ¼ cc. at a time until the lather is permanent, when the bottle can be laid on its side for three minutes with no decrease in the lather. The bottle must be well shaken after each addition of soap solution. In Clark's Table of Hardness* opposite the number of cubic centimeters of soap solution used will be found the degree of hardness in parts per million.

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* Gill's "Engine Room Chemistry," p. 105; also M. E. Pocket-book, 8th Ed., p. 694.

Permanent Hardness.—This is obtained by subtracting the degree of temporary hardness, that due to the bicarbonates, and lessening by boiling, from the total hardness. The result is expressed as before in parts of calcium carbonate per million parts of water.

Temporary Hardness.—Each cubic centimeter of the test solution used indicates 0.001 of a gram of $CaCO_3$ per million. In using, proceed as follows: Dilute 25 cc. of raw water with 75 cc. of distilled water and add five drops of methyl orange indicator, which will turn the solution a yellowish tinge. Now add the acid solution drop by drop until the color of the solution turns from a yellowish to a rose pink. The number of cc. of the HCl solution used multiplied by 4 will be the temporary hardness expressed as calcium carbonate in parts per million.

Analysis of Softened Water.—Measure out 100 cc. of the purified water, put it into a beaker and add a few crystals of barium chloride. The addition of four drops of phenolphthalein indicator will turn the solution purple if there is plenty of lime present. Now add standard acid solution drop by drop to obtain a clear solution. This is analysis for lime. The number of cubic centimeters of acid solution added indicates the amount of lime present, as explained above, and may be read off directly from the graduation on the burette. Measure out another 100 cc. of the softened water, add four drops of the phenolphthalein solution and titrate with the standard acid solution to obtain a clear solution as before. Call the result in the first operation B and the result in the second operation A. Then A minus B in cubic centimeters multiplied by 0.091 equals the number of pounds of soda ash required for 1000 gallons; B multiplied by 0.048 equals the number of pounds of lime per 1000 gallons.

Methods for Purification of Water.*—The more or less complete removal of scale-forming matter or the neutralization of corrosive substances which occur in boiler feed-water has been carried out by several methods in the United States.

The methods may be classified as follows:

I. MECHANICAL METHODS.

These include feed-water heaters, scum-catchers and blow-off cocks.

II. CHEMICAL METHODS.

(*a*) *Direct Method.*—The chemicals are placed in the boiler or run into it with the water supply.

(*b*) *Indirect Method.*—The chemicals are fed into the water on its way to a storage tank which serves also for the completion of chemical reaction and for sedimentation.

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* Abstract of a paper by J. O. Handy, read before the International Congress, St. Louis, October 3 to 8, 1904. *Elec. Review*, Nov. 12, 1904.

(*c*) *Intermittent Method.*—The chemical treatment is given alternately to the contents of two tanks, allowing reaction and sedimentation to take place during periods of quiet. Partially clarified water is drawn off through filters and repumped to storage tanks.

(*d*) *Continuous Method.*—The chemical treatment is given automatically to the water as it enters the apparatus. The chemical reaction, sedimentation and clarification take place simultaneously or successively during the progress of the water through the apparatus.

CLASS I—MECHANICAL METHODS.

Feed-water heaters remove more or less completely from water the carbonate of lime which it contains, but more important scale-forming substances are not affected and pass on into the boiler, from which it is impossible to remove them except very imperfectly by scum-catchers or blow-off cocks.

Sulphate of lime deposits as scale in boilers very gradually with increasing concentration. Pressure and temperature have a modifying influence on the rate of deposition, but no temperature is reached in steam boiler practice at which sulphate of lime immediately falls out of solution.

CLASS II—CHEMICAL METHODS.

2 a—Direct Method.—This practice is very general in the United States and the beneficial results obtained have been in exact relation to the judgment shown in selecting the chemicals and the care shown in carrying out the details of the treatment. Soda ash has been most widely employed. Used without discrimination, it is rarely beneficial.

The experience of the Chicago, Milwaukee and St. Paul Railway proved conclusively that the systematic use of soda ash, combined with regular blowing off of the sludge produced by chemical action, was a measure of great economic importance.

Principle: "When waters are treated in the boiler with soda ash, the incrusting solids are changed to carbonates and precipitated as a soft sludge which is readily blown out, instead of coming down in a crystalline condition and adhering to the boiler."

AMOUNT OF SODA ASH USED

For Each Grain per Gallon.	Soda Ash per 1000 Gallons.
Calcium carbonate	0.02 lb.
Magnesium carbonate	0.02 "
Calcium sulphate	0.10 "
Magnesium sulphate	0.13 "
Magnesium chloride	0.16 "

Limitations of Direct Soda-ash Treatment.—Boilers must be more frequently washed out, because blowing-off does not completely remove

sludge. Foaming occurs frequently, due partly to suspended sludge and partly to the presence of carbonate of soda in variable excess in the water. Very hard water cannot be treated sufficiently to prevent scale formation without introducing soda enough to cause foaming.

Aside from its price, which is about four times that of soda ash, phosphate of soda has certain advantages. It produces by its action on the lime salts in the water, flocculent, amorphous precipitates which are absolutely non-adherent to boiler surfaces and are easily blown out.

Limitations of Tri-sodium Phosphate.—The price, taken together with its high combining weight, makes it at least nine times as expensive as soda ash for water-softening purposes. It cannot be used for complete softening of cold water because the chemical reactions are not finished in any reasonable time without heat. Magnesia precipitates very slowly. The precipitate is bulky and an apparatus with unusual sludge room would be required.

Lime and Soda Ash.—In the treatment of acid waters from coal mines and washers, some large steam users have kept their boiler water supply neutral by means of milk of lime fed proportionately through feed pumps. Others have used soda ash alone. The best practice for acid waters is the use of lime and soda ash in equivalent amounts.

The lime treatment leaves sulphate of lime, a scale-forming substance, in the water. The soda-ash treatment leaves free carbonic acid in the water and the iron salts are incompletely removed in consequence. Foaming is also encouraged by the carbonic acid gas. No by-products of injurious nature are formed when dilute caustic soda, or lime + soda ash are used for acid waters.

Of all the chemicals available for direct treatment of boiler feed water, sodium phosphate is best and soda ash and lime next. Any direct treatment should be regarded merely as a temporary expedient to be superseded by softening machines as soon as conditions permit.

2 b—Indirect Method.—Treatment of water by the introduction of chemicals into the water as it flows to the storage tank was the first step in the evolution from direct treatment toward complete softening machines. This method has no feature to recommend it except low first cost. In their simplest, crudest form, the plants consist of:

1. An arrangement for supplying chemical solution at approximately the required rate from a barrel attached to the suction of the supply pump.

2. A floating draw-off in the service so that approximately clear water may be drawn from it.

3. A dump valve in the bottom of the service tank for sludge removal.

Having usually only an imperfect chemical proportioning device, no arrangement for ensuring steady progression of water through the storage tank, and no provision for drawing off more than part of the

sludge without emptying the tank, such plants do only imperfect work.

2 c—Intermittent Method.—The devices under this heading are intermittent in operation in that there is a pause of several hours after treatment. This is to give the time considered necessary for chemical reaction and sedimentation.

In the commercial development of the intermittent system of water softening, N. O. Goldsmith, of Cincinnati, Ohio, and J. B. Greer, of Pittsburgh, Pa., have done important work. Many of their plants have been installed in the United States and the systems are styled, respectively, the "We-Fu-Go" and the "Ideal." Their work dates principally from the year 1896.

They added to previous practice in the country the following points.

The use of milk of lime instead of lime water.

The use of sand filters to clarify the softened water.

The "We-Fu-Go" plants have paddle stirrers, while the "Ideal" plants use compressed air for mixing and agitating purposes. There are no other essential differences.

The general plan of operation is as follows:

Two tanks are provided, the aggregate capacity of which is usually eight times the hourly output expected. These may be of either wood or iron construction and may be placed on ground level or elevated on trestle-work according to whether repumping of softened water is to be allowed for or avoided.

The tanks are filled alternately to a certain level with hard water. In some plants the milk of lime is added during the filling and the agitator is run at the same time. In most of the plants, the Archbutt-Deeley practice of dissolving the soda ash in the milk of lime and adding both together when the tank is filled, is the one followed.

Agitation continues for fifteen to twenty minutes, followed by a period of perfect rest usually approximating four hours.

At the end of this time the softened water is drawn off from near the surface through floating discharge pipes. It passes through sand or crushed quartz filters to storage tanks from which it is repumped to a higher elevation if necessary.

Intermitting Softening Plants for Hot Water.—Almost all chemical relations are hastened by the application of heat. A hot water plant can be operated with smaller tanks than a cold water one.

The Solvay Process Company's Purifying System.—Onondaga lake water is used. The water is hard and saline.

	Parts per 100,000
Calcium bicarbonate	14.38
Magnesium bicarbonate	1.32
Calcium sulphate	22.88
Calcium chloride	4.90
Magnesium chloride	72.27
Sodium chloride	97.90

Sodium carbonate (soda ash) is the purifying agent used, 25 per cent in excess of the calculated amount being placed in each of two 4300-gallon tanks before the water enters. The water is at 178° F. (having been used in condensers). It enters the tanks at the rate of 13,000 gallons per hour, which means that three tanks are filled and emptied hourly, making the cycle for one tank twenty minutes.

This plant is interesting because of the small tankage and the high rate of purification. The reaction-tank area is only two-thirds of the hourly output, and there are no mechanical devices to facilitate mixing or hastening the mechanical reaction. The high temperature of the water to be treated and the fact that 25 per cent excess soda ash is used, explains the success of the process. The treated water is pumped through sand filters into the boilers. Seven filters, from four to six feet in diameter by four to five feet high are used.

After passing the filters the water contains lime salts equivalent to 2.50 parts sulphate of lime per 100,000. The boiler tubes show a dust-like coating, easily rubbed off. By blowing off at intervals the concentration of sulphate of soda, carbonate of soda and salt is kept at or below 2° Baumé (hydrometer). One man on each eight-hour shift attends to the treatment.

2 d—Continuous Method.—The type of machine referred to is one so designed that the flow of water to the plant operates all necessary mechanism (stirrer, etc.). The feed of chemicals is regulated by proportioning devices. Proper mixing of chemicals with hot water takes place automatically and the water passes evenly through the machine, while the chemical reaction of softening proceeds and sedimentation is almost perfectly effected. A filter at the top of the machine gives final clarification and the softening water is discharged without repumping into the storage tank.

Desrumeaux utilized by means of a water-wheel the power of the water flowing into the softening machine for driving a stirrer in his lime tank. In both lime-water and reaction tanks, he had annular, spiral passageways for the rising water, aiming to give it a steady, curcuitous upward movement. Sludge settling on the spiral plates was supposed to slide to outlets properly placed to favor undisturbed fall to the base of the machine. The feed for chemicals was controlled by valves operated by floats in the hard-water box.

The design has been modified by Mr. C. H. Koyl. The spiral settling device was discarded; the small lime-water tank was replaced by a very large one, and elaborate stirrers were placed in the reaction tank.

The lime-water tank is made large so that it will produce practically clear saturated lime water of definite strength and not milk of lime. The rate of clarification varies according to whether hard water or soft water is used for making lime water.

Stirring always assists chemical reaction, but machines with no stirring beyond about five minutes' mixing turn out properly softened water. The course of the water through the apparatus as effected

by its internal design is a very important factor in determining the completion of reaction and sedimentation.

The Kennicott water softener differs in the following respects from other continuous softeners: 1, the chemical feed-proportioning device; 2, the use of soft water for lime water; 3, method of mixing chemicals and hard water; 4, means of assisting sedimentation; 5, compact, concentric tank arrangement.

The proportioning devices employed in connection with continuous chemical feed in the several softening machines used in this country are: 1, Weirs; 2, stopper valve actuated by tipping-bucket; 3, pumps actuated by tipping-bucket; 4, spoons actuated by tipping-bucket; 5, fixed orifices for discharge; 6, movable and adjustable orifices for discharge.

Continuous Systems for Hot Water.—Any system or plant which fulfils the conditions for softening cold water will necessarily soften hot water. Steel construction is best and smaller tanks may be used. Nevertheless, it is a mistake to sacrifice anything in thoroughness of mixture or means of securing uniformity of progress of water through the apparatus.

The typical continuous hot-water plant consists simply of: (*a*), soda and lime-water tanks; (*b*), separate feed pumps; (*c*), mixing tank with baffle partitions; (*d*), sand filter.

The chemical feed pump may be coupled up with the hard-water feed pump, but in many cases this is not done and the only means given the operator to judge of accuracy of feed is a bottle of phenolphthalein solution. As this reagent gives a pink color as soon as the free carbonic acid in the water has been neutralized, it does not indicate whether lime enough has been added to decompose bicarbonates and soda enough for other lime and magnesia salts.

Hot water softening had best be carried out with an apparatus having more reliable chemical feed devices than proportional pumps.

The Economic Results of Water Softening.—The considerations which lead to the taking up of water softening by steam users may be grouped as follows:

First.—Loss of service of boilers, due to impossibility of satisfactory continuous operation with hard water.

Second.—Possibility of substantial savings in fuel and repair bills and the checking of rapid deterioration of boilers.

The charges against a water softening installation are:

Interest on cost of plant.
Depreciation.
Chemicals for softening.
Attendance.
Power for operation (and repumping).

The credit items for a softener are:

Fuel saving.
Repair saving.

Depreciation saving.

Increased service obtainable from steam generators.

Cost of Softening Plants.—The best softening plants with steel construction cost from $4 to $5 per H.P. for installations up to 1000 H.P; for 1000 to 2000 H.P., $4 to $3; 2000 to 5000 H.P., $3 to $2; 5000 to 15,000 H.P., $2 to $1.20 per horsepower.

Cost of Chemicals.—Much of the building lime is so high in magnesia as to make it unfit or uneconomical to use. From 90 to 95% lime can be had and should be insisted upon.

The cheapest waters to soften are those the hardness of which is due to carbonates of lime and magnesia only. Such waters require simply lime-water treatment. It costs only 0.2 cent per 1000 gallons to remove 1.42 pounds of carbonate of lime (equivalent to ten grains per gallon) and only 0.48 cent to remove the same quantity of carbonate of magnesia. These amounts are sufficient to give a great deal of trouble in heaters and boilers.

The removal of sulphates and other soluble compounds of lime and magnesia from water requires the use of soda ash. It costs 1.20 cents per 1000 gallons to remove sulphate of lime equivalent to ten grains per United States gallon. The same amount of sulphate of magnesia requires 1.36 pounds of soda ash which costs 1.36 cents per 1000 gallons.

The cost of chemicals for softening water varies from 0.5 cent to 5 cents per 1000 gallons, averaging from 1 to 2 cents.

The cost of attendance at softening plants varies greatly. With the best type of plants two or three hours per day are all that are required for attendance unless the installation is very large. Chemical tests for control of the softening plant can be carried out by persons of average intelligence. The best plants have all stirrers or other mechanism actuated by water power. The flow of water to be softened starts everything.

The Permutit Water-softening Process.—"Permutit" is the name given to a porous mineral compound obtained by fusing together felspar, kaolin, sand and soda. This substance placed in an ordinary iron tank removes the hardness by exchanging, as the water passes through it, the lime and magnesia, which cause the hardening, for an equal amount of sodium.

All that is required, after the tank has been set up, is that the crystals be placed in the tank and the water turned on. Because of the chemical change which occurs by the exchange of sodium for magnesium and lime, the compound has to be regenerated when the sodium becomes exhausted. When this exhaustion occurs, the regeneration is accomplished by running a solution of common salt through the "permutit." This done, the filter is ready for work

again, as good as new. The cost of maintenance is only the price of common salt.

Permutit is an artificial sodium zeolite of the formula $2SiO_2$, Al_2O_3, Na_2O, $6H_2O$. The reactions with lime carbonate and sulphate, the permutit being designated by P, are

$$PNa_2 + CaH_2(CO_3)_2 = PCa + 2NaHCO_3.$$

$$PNa_2 + CaSO_4 = PCa + Na_2SO_4.$$

The regenerating reaction is as follows:

$$PCa + 2NaCl = PNa_2 + CaCl_2.$$

The filtering apparatus may be either of the open or of the closed type. In either type, the charge of permutit rests on a bed of crushed flint, and a similar bed of flint, carried on a perforated plate, is placed in the upper part of the filter to prevent the escape of permutit during the regenerative process. The depth of the charge is determined by the hardness of the water and the speed of softening required. Hard water may be perfectly softened by passing it through a layer of permutit 24 to 40 inches in depth at a rate of 10 to 16 feet an hour, and the speed of filtration usually adopted lies between these limits. The permissible speed of filtration can be raised by increasing the depth of permutit charge, but it is limited by the fact that for efficient action the water must have time to penetrate the interior of the grains. The extreme limits of speed are: For water containing 0.01 per cent lime, approximately 27 feet; 0.02 per cent., 16 feet; and 0.03 per cent, 10 feet an hour. The volume of water treated depends, of course, on the area of the charge.

The regenerating solution generally used contains about 10 per cent of sodium chloride, and to facilitate the action the solution is usually heated to 100° to 120° F.

Admission of the solution to the filter is regulated automatically at a very slow rate to permit the solution thoroughly to penetrate the grains of permutit. Admission occupies 4 to 5 hours, and when the charge is completely impregnated the solution is left in the filter for about the same period. The charge is then drained and washed thoroughly to remove all traces of salt. Since the regenerative process is completed in about 8 hours, where continuous service is required two filters are necessary for alternate purification and regeneration.

The sole precaution necessary is that the concentration of the soda

salts in the boiler shall not exceed 2.5 to 3 per cent. (From circulars of The Permutit Co., New York.)

The Eureka Water-softening Apparatus, made by the Dodge Manufacturing Co., is shown in Fig. 240. It consists essentially of two portions, the smaller a lime-saturating tank, and the larger a decanting tank, for precipitation of the scale-forming constituents after being acted upon by the lime solution and reagents. The water to be treated enters the top tank *B* and is divided for delivery, a small portion to the saturator *J*, the greater portion to the decanting tank. On its way to the decanting tank, the water passes over a wheel *E*, whose rotation actuates stirrer arms in the saturator. The saturator *J* provides a continuous supply of saturated lime solution, which is fed with other reagents in proper proportions, under automatic control, from a small tank *G* into the central tank *M* of the decanter. Here the reaction takes place, the water passing downward and returning upward in the main body of the large tank, passing spirally among the slant-settling plates *N*. On these spiral surfaces the scale-forming matters and other impurities are deposited in flakes which gravitate freely to the conical bottom of the main tank, whence they may be passed off into the sewer by occasional opening of the valve *S*. Any sediment forming at the bottom of the lime saturator tank may similarly be blown off through the valve *U*. The water itself, continuing upward, passes through filtering material *A* into an annular space, whence it is drawn off as wanted. The water is treated cold by means of reagents which may be bought in market at a trifling cost. All the attention required is to renew daily the lime and other reagents in prescribed proportions and to flush out the accumulated slush by opening the valves *S* and *U*.

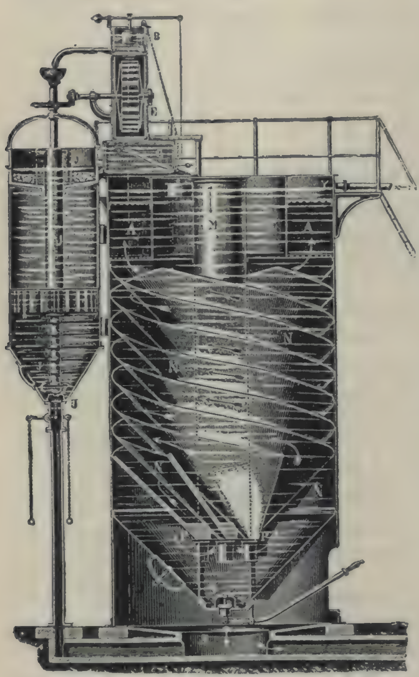

Fig. 240.

External Corrosion is a frequent cause of dangerous weakening of a steam-boiler. It is most commonly due to dampness, and is there-

fore more liable to take place when a boiler is out of service and cold than when it is in use and constantly kept hot. The most active agent of corrosion is sulphurous acid gas, produced from the sulphur in the coal, which is converted into sulphuric acid in the presence of moisture in the cold. Mud-drums and other parts of a boiler which are farthest removed from the fire, and on which there is apt to be an accumulation of damp soot or dirt, are especially subject to external corrosion. The precautions to be taken to prevent this kind of corrosion are to have the boiler frequently inspected and to keep it clean, dry, and hot.

The Life of a Steam-boiler.—What is known as the "life" of a boiler generally depends upon the amount of corrosion to which it is subjected. With good feed-water which will neither corrode the metal nor cause the deposit of a dangerous scale, and with care to keep the outside surface perfectly dry, a life of forty years for a boiler is not uncommon. With slow corrosion its life may be reduced to five years or less, with the additional inconvenience that the pressure of steam which may be safely carried is continually being reduced during its life.

Besides corrosion other causes tending to shorten the life of a boiler are: (1) Tendency to accumulaton of scale, mud, or grease on the plates over or near to the fire, causing "bagging" of plates, leakage of seams, and sometimes explosions. (2) Overheating of riveted seams where they overlap, especially when they are covered with scale. (3) Hidden defects, due to strains or other causes, such as those described below.

Defects Discovered by Inspection.—*The Locomotive*, published by the Hartford Steam-boiler Inspection and Insurance Co., gives the following statement showing the number and kind of defects discovered by the inspectors of that company during the year 1912. (See table at top of p. 548.)

Explosions Caused by Hidden Defects.—It is the common opinion that explosions are due to carelessness of handling by the firemen, or to negligence of inspectors in not discovering defects, but occasionally an explosion takes place which is not due to either of these causes. On February 27, 1897, a disastrous explosion took place at the Acushnet Mills, New Bedford, Mass., wrecking a portion of the mills and killing and injuring several persons. The boiler that exploded was built in 1890. Examination showed that the break was almost identical with that of the explosion of a boiler at the Langley factory,

Number of visits of inspection made	183,519
Total number of boilers examined	337,178
Number found uninsurable	977

Nature of Defects.	Whole Number.	Dangerous.
Cases of sediment or loose scale	26,299	1,553
Cases of adhering scale	40,336	1,436
Cases of grooving	2,700	252
Cases of internal corrosion	15,403	823
Cases of external corrosion	10,411	895
Cass of defective bracing	1,391	331
Cases of defective staybolting	1,712	345
Settings defective	8,119	768
Fractured plates and heads	3,288	510
Burned plates	4,965	517
Laminated plates	445	55
Cases of defective riveting	1,816	405
Cases of leakage around tubes	10,159	1,607
Cases of defective tubes or flues	11,488	4,780
Cases of leakage at seams	5,304	401
Water-gages defective	3,663	816
Blow-offs defective	4,429	1,398
Cases of low water	447	151
Safety-valves overloaded	1,349	380
Safety-valves defective	1,534	419
Pressure-gages defective	6,765	568
Boilers without pressure-gages	633	102
Miscellaneous defects	2,268	420
Total	164,924	18,932

Fall River, Mass., in June, 1895, which boiler was made by the same builders that made the boiler in New Bedford. The boiler parted in a horizontal seam of the middle sheet, close to the rivet-holes, and under the lap, and the fault was owing to a crack in the plates

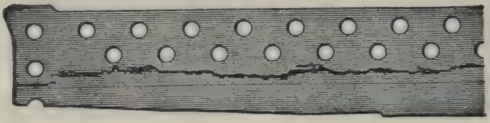

FIG. 241.—A HIDDEN CRACK.

under the outer edge of the rivet-heads, as shown in the accompanying cuts, Figs. 241 and 242. *The Locomotive,* speaking of this class of fractures, says:

Most of the fractures of the plate are undoubtedly due to the bending of the plates in the rolls. From 30 to 40 per cent of the sectional area of the plate is removed along the line of the joint by

punching or drilling the rivet-holes; and when the part that is thus weakened is passing through the rolls, the curvature of the plates at this point is sensibly increased. When the plates thus affected are brought into position for riveting they will not lie closely, but have to be knocked together with a sledge, or forced together hydrostatically, before the rivets can be driven. This means that there is a severe local strain left in the plates, the effects of which are likely to become visible at some time in the subsequent history of the boiler. When the joint has been riveted up, the parts of the plate that lie under the heads of the rivets are held together so firmly that the yielding action that occurs in every boiler, as the pressure and temperature vary, will not be felt at this point, but will be transferred to a line lying at, or just beyond, the edge of the rivet-heads. In the course of time these slight changes of form, when combined with the stress already existing along this line from the cause just described, are likely to develop a crack starting from the inside surface of the outer plate, at a place completely hidden from view, and extending insidiously outward, until the final rupture of the plate is accomplished, and the boiler gives way in a violent explosion.

FIG. 242.—SECTION OF SEAM.

Here is the record of an explosion due to a cause that had been concealed for seven years, and which cause was so hidden that it could not be found by either external or internal inspection.

FIG. 243.—BUTT AND STRAP JOINT.

It may be said that this accident and that at the Langley mill, in 1895, would not have happened if the boilers had been properly made, and if the riveted joint had been of the form shown in Fig. 243, but it must be remembered that the horizontal tubular boiler is favored chiefly on account of its low first cost, and low cost is generally not compatible with the highest excellence of material and workmanship. If a cheap form of boiler is selected and the contract given to the lowest bidder, it is only to be expected that cheap material, cheap workmanship, and unskilled designers are likely to be employed in its construction.

The water- and steam-drum of a water-tube boiler being much smaller than the shell of a fire-tube boiler, and costing a much smaller percentage of its total cost, there is not the same temptation to make the drum cheap that there is with the shell boiler.

Causes of Boiler Explosions. (W. H. Boehm, *Power*, Oct. 8, 1912).—Boiler explosions may be attributed to improper construction, improper installation, or incompetent or careless operation.

Improper construction may consist: of unsuitable or inferior material; poor workmanship; abuse of material, as when unmatched rivet holes are drift-pinned to place, or uncylindrical shells are sledged to form; or employing the more dangerous lap joint for the side seams instead of the more safe and more sensible butt joint.

The lap joint in new boilers should be prohibited by law in all States, as it now is in some.

Improper installation may consist of so supporting the boiler and its piping as to allow temperature changes to set up dangerous stresses in the material, of improperly attaching the usual appurtenances such as safety valves, steam and water gages, check, blow-off and stop valves.

Incompetent or careless operation may consist in allowing the steam gage to get out of order, in allowing the water-gage connections to become so clogged as to indicate ample water when there is none in the boiler, in allowing the safety valve to become so stuck to its seat as to fail to blow at the pressure for which it was set, in allowing grease to enter or scale to accumulate in the boiler, in allowing large quantities of cold water to impinge against hot plates, in allowing the water to be driven from the heated surfaces by forced firing, in allowing a large valve to be opened too suddenly, in allowing two boilers to be cut in on the same steam main when their pressures are unequal, and in allowing minor repairs to be neglected until they endanger the whole structure.

Many violent boiler explosions occur either just prior to the starting of the engines in the morning, or while they are idle at the noon hour, or shortly after they have been shut down for the day. One reason is that when steam is not being drawn from the boiler it accumulates rapidly; and if the safety valve fails to relieve the pressure, explosion soon follows.

The rapidity with which the bursting pressure is reached may be shown as follows:

Let T = time in minutes required to reach the bursting pressure;
W = weight of water in the boiler;
t = temperature of the steam at bursting pressure;
t' = temperature of the steam at normal working pressure;
U = number of heat units per minute supplied by the furnace and absorbed by the water.

The heat balance is then represented by the equation:

$$UT = W(t-t'); \qquad T = \frac{W}{U}(t-t').$$

Take, for example a 100 H.P. boiler containing at normal level 5000 lbs. of water and suppose it uses 50,000 heat units per minute when evaporating 50 lbs. of water per minute. Then if the normal gage pressure be 85 lbs., the corresponding temperature of the steam is 327 deg., and if the bursting gage pressure be 485 lbs. the corresponding temperature of the steam is 467 deg.; and the time required to reach the bursting pressure with all steam openings closed and the safety valve stuck is:

$$T = \frac{5000}{50000}(467 - 327) = 14 \text{ minutes.}$$

That is, with a stuck safety valve, only 14 min. would elapse from the time the engines were shut down until the explosion followed:

If the fire be drawn when the openings are closed, ebullition ceases. If a valve be opened, ebullition starts again, even though there still be no fire under the boiler.

With the openings closed it is the pressure on the surface of the water that prevents further generation of steam. If a small rupture occurs below the water line a violent explosion may not ensue. But if a large outlet above the water line be suddenly opened, as, for example, when a steam pipe fails, then the sudden liberation of the pressure on the surface of the high-temperature water will allow it to flash suddenly into steam and cause a violent explosion and water-hammer that will disrupt the strongest possible construction.

Grease in Boilers.—Grease does not dissolve or decompose in water, nor does it remain on the surface. Heat in the water and its violent ebullition causes the grease to form in sticky drops which adhere to and varnish the metal surfaces of the boiler. This varnish by preventing the water from coming into intimate contact with the metal, prevents the water from absorbing the heat, and this causes a blistering or burning of the plate that often results in a serious rupture, or a violent explosion.

Scale in Boilers.—If scale is allowed to accumulate to any considerable thickness in a boiler, a bag or rupture of the shell is inevitable, unless the scale happens to be of a spongy formation, which is not often the case. Just why this is so, is shown by the following simple experiment.

Take an ordinary granite iron or tinned iron stewpan and firmly glue to its underside a postage stamp. Pour water into the pan and place it on a gas stove so that the postage stamp will be in direct contact with the flame. Leave the pan on the stove until the water has boiled violenty and then examine the stamp. The stamp will not even be charred, much less burned, notwithstanding that it was on the underside of the pan and in direct contact with the hottest part of the flame.

Now put into the pan a mixture of water and portland cement half an inch thick. This, when set, will be the equivalent of half

an inch of scale. Repeat the experiment made before and it will be found that the stamp will burn up very quickly.

The reason that the postage stamp is not charred by the flame when no scale is present is that the water, being in immediate contact with the thin bottom of the vessel, absorbs the heat as fast as it is put into the vessel by the flame. The result is that, no matter how hot the flame may be, the bottom of the vessel remains at practically the same temperature as the boiling water with which it is in contact. In an open vessel the temperature of boiling water, 212 deg., this is not sufficiently high to char paper. When scale is present, the water cannot absorb the heat as fast as it is put into the vessel by the flame, and as a result the temperature becomes greater than 212 deg. and burns the postage stamp.

It is the same with steam boilers. If the water comes in direct contact with the thin plates, the heat is absorbed, the temperature of the plates remains practically the same as the water, and no harm is done. If there be a considerable thickness of impervious scale in the boiler, the water cannot absorb the heat as fast as it is put into the plates by the furnace, and so the plates become overheated, get red, become plastic, and finally give way to the force of steam pressure, causing a bag, or a rupture, or a violent explosion.

Scale endangers the safety of boilers in other ways. It clogs the feed pipes, preventing the feed water from freely entering the boiler. It clogs the connections to the water gage, causing it to indicate ample water when it is at a low level in the boiler. Pieces get under valves and prevent their closure.

Scale in boilers is a serious matter, and in order to prevent its accumulation, it is good practice to eliminate the scale-forming matter from the feed water before allowing it to enter the boiler. This can be accomplished either mechanically by means of separators, or chemically by treating the water in vats especially arranged for the purpose. If preferred, compound may be fed with the water into the boiler, but in such case the water should be analyzed, and the proper compound prescribed by a chemist making a specialty of such matters. Kerosene fed into the boiler has proved beneficial in many instances.

Inspection and Insurance.—It is an almost universal custom for boiler owners to have their boilers insured and inspected. The insurance serves as a guarantee that the inspections will be intelligently and carefully made and the inspections lessen the chance of accident.

When boiler insurance is carried, an inspector visits the plant at regular intervals and critically examines the boilers, both internally and externally. During the past 10 years the company represented by Mr. Boehm made 1,101,140 examinations and reported 140,989 defects, many of which consisted of dangerous fractures in or near the riveted seams, and that one boiler out of every eight examined, contained defects serious enough to warrant their being reported.

Clinkering in Furnaces.*—Clinkering increases the cost of the heat liberated from the coal (1) by decreasing the efficiency and capacity of the furnace, (2) by increasing the labor cost, and (3) by shortening the life of the fire-bars and of the fire-brick lining. Occasionally it may interrupt entirely the operation of a plant, as when a badly clinkering batch of coal, used on a chain grate, clogs up the moving parts entirely.

Clinkering is a result of fusion and is some function of the fusibility of the ash. The fusing temperature of an ash is not generally a single-valued temperature. At some particular temperature, some one constituent of the ash will melt; if it is a minor constituent the effect may be that the ash becomes a viscous pasty mass. At higher temperatures other constituents may melt and the mass will become more liquid. In other cases, the ash may become liquid as soon as the initial melting temperature is passed. If the melt is very viscous, we shall get a sticky mass which will attach to itself the surrounding coal and ash and form a troublesome clinker; if it is more fluid it will run on the grate bars and will in part freeze there and may be difficult to detach; if it is extremely fluid and melts at a temperature very much below that of the fire, it might possibly flow from the fire like water and give very little trouble.

The chemical compounds in ash are principally the oxides of aluminium (Al_2O_3), of silica (SiO_2), of iron (FeO or Fe_2O_3), of lime (CaO), of potash (K_2O), of magnesium (MgO), of sodium (Na_2O), of sulphur (SO_3), and to a lesser degree of manganese, phosphorus, zinc, lead and other elements. Chemical analysis will disclose the weights of these constituents but will in general fail to show how they are combined with one another.

Alumina (Al_2O_3) is the most infusible, melting at a temperature higher than 3450° F.; silica melts at about 2600° F. A mixture of alumina and silica melts at some intermediate temperature, the temperature falling as the silica increases. One part of alumina with five parts of silica melts at 3180° F.; one part of alumina with ten parts of silica at 3075° F. A comparatively small amount of alumina has a considerable influence in raising the temperature of fusion of silica.

The temperature in a boiler furnace is probably never greater than 3200° F.—usually it is considerably less. It is obvious then, that a mixture of alumina and silica will be infusible in a boiler furnace so long as a minimum of 10 per cent of alumina is present. But there is very little coal ash with as little as 10 per cent of alumina. The usual amount is from 20 to 40 per cent.

The iron and other compounds that are present may all be regarded as fluxes, tending to reduce the melting point of the alumina-

* Condensed from a paper by Professor Lionel S. Marks in *Engineering News*, Dec. 8, 1910.

silica mixture. When the constituents are mixed in such proportions as to give the lowest fusing temperature, we have what is called the "eutectic" mixture. A mixture of 45 per cent of SiO_2 with 55 per cent FeO melts at 2050° F.; with 10 per cent CaO substituted for FeO, we get the eutectic melting at 1940° F.; with 45 per cent of CaO substituted for FeO, the melting temperature rises to about 2460° F. A mixture of 32 per cent SiO_2, 36 per cent FeO and 32 per cent CaO melts at 2100° F.; with 5 per cent of the CaO replaced by Al_2O_3 we get the eutectic, melting at 2030° F.

It is probable that an ash will not give trouble by clinkering under usual furnace conditions when the fusing temperature is above 2700° F. and that the trouble experienced will increase as the melting temperature falls below this temperature, for a range of several hundred degrees. In the present state of knowledge it is impossible to tell from a chemical analysis what will be the fusing temperature and how much trouble will arise from clinkers. Further, the fusing temperature is not always a definite temperature but may cover a considerable range of temperatures. The trouble from clinkers also depends on the viscosity of the melt, which is not a function of melting temperatures.

The influence of sulphur is undoubtedly considerable in some cases, but the clinkering depends on the percentage of sulphur in the ash, rather than the percentage of sulphur in the coal. High sulphur is commonly accompanied by high ash, and the sulphur is not then necessarily very troublesome. As much as 5½ per cent sulphur may exist in a coal without causing clinkering. When, however, the percentage of sulphur in the ash is high, much clinkering is likely to result. The effects of sulphur are well set forth as follows in the report of the U. S. Geological Survey (Bulletin 325.):

> Sulphur is an undesirable element in coal. It generally occurs in combination with iron as iron pyrites, and in combination with calcium, as calcium sulphate, or gypsum. Pyrites can readily be recognized by its heavy weight, bright brass-like color, and crystalline structure. The calcium sulphate occurs in small, thin, white flakes, more or less transparent. Of the two sulphur compounds, the pyrites is generally in larger quantity in coal, and is harmful because it increases the tendency of the coal to clinker. The clinkering is especially bad if the percentage of ash is small in proportion to the sulphur. In such coals, the pyrites and the ash fuse together and form a thin layer of solid clinker, which effectively stops the passage of air through the grate, thereby permitting the grate bars to become heated from the hot fuel bed just above. The clinker then melts down into the spaces between the bars and the sulphur seems to combine with the iron of the grate. The heat warps the grate bars, and the clinker has such corrosive action on the hot iron that a set of grate bars is destroyed in the course of a few days. When such clinkering occurs any attempt to slice the fire fails, and only slow and very difficult cleaning of the fires will remove the clinkers.

A common view as to clinkering is that it is caused by iron. The presence of iron certainly results in a lowering of the melting temperature—and so far as the presence of iron means the presence of

sulphur, there may be that secondary reason for clinkering. The tests of the U. S. Geological Survey show a decided increase in the percentage of clinker in the refuse, as the percentage of iron in the coal increases.

It is probable that the fire-bars waste away, wherever contact takes place with molten iron or with ordinary molten clinker, in two ways: (1) by direct melting and, (2) by chemical combination or solution. The latter is undoubtedly the more active agent, since it will in general result in a lowering of the melting temperature of the cast iron and may be accompanied by evolution of heat.

The size of coal has apparently no effect on clinkering. No variations can be detected in the formation of clinker when the size of the coal is changed.

The possible methods for preventing clinkers are:

(1) Reducing the temperature of combustion in the furnace. This can be accomplished by sending more air through the fire, but it will always be accompanied by a reduction in efficiency.

(2) For coals high in ash, the use of steam blown in from below the grate will prevent the clinkers freezing on the grate, and will permit longer periods of operation between cleanings of the fire. With some clinkers this method is not found to give much relief.

(3) The fusing temperature or viscosity of the ash might be raised by mixing certain substances with the coal so as to prevent either the fusing of the ash or the flow after fusing.

(4) The fusing temperature and viscosity might be so much reduced by the admixture of various fluxes, that the fused material would run through the grates like water without freezing on them.

A series of experiments on methods (3) and (4) was carried on by Prof. Marks, but the results were practically unimportant.

The results of the inquiry are summed up as follows: The elements the presence of which cause trouble from clinkering are principally calcium, iron and sulphur. The exact amounts of these which may be present without causing trouble is not at present known with sufficient accuracy to permit the use of a formula (such as Prost's) with any security. The only real cure for clinkering is low-temperature combustion. If the temperatures are high the trouble from clinkering can generally be reduced by the use of steam, or by the addition of kaolin or pure quartz, both of which, however, are too expensive to be commercially justifiable.

The author has had considerable experience with clinkering coals, and would add to the remedies suggested by Prof. Marks the following:

1. Large grate surface, reducing the rate of combustion and the amount of clinker formed per square foot of grate.

2. Low temperature combustion on the grate produced not by an

excess but by a deficiency of air, the combustion being completed with an additional air supply in a fire-brick combustion chamber removed from the grate.

3. Shaking and dumping grates, to remove the clinker before it is formed in large masses.

CHAPTER XVI.

EVAPORATION TESTS OF STEAM-BOILERS.

Object of an Evaporation Test.—The principal object of an evaporation test of a steam-boiler is to find out how many pounds of water it evaporates under a certain set of conditions in a given time, and how many pounds of coal are required to effect this evaporation. The test may be made for one or more of several purposes, viz:

1. To determine whether or not the stipulations of a contract between the seller and the buyer of a boiler (or of an appendage to the boiler, such as a furnace) have been performed.

2. To determine the relative economy of different kinds of fuel, of different kinds of furnace, or of different methods of driving.

3. To determine whether or not the boilers, as ordinarily run under the every-day conditions of the plant, are operated as economically as they should be.

4. To determine, in case the boilers either fail to furnish easily the quantity of steam desired, or else furnish it at what is supposed to be an excessive cost for fuel, whether any additional boilers are needed or whether some change in the conditions of running is a sufficient remedy for the difficulty.

For the first of the above-named purposes, it is necessary that the test should be made with every precaution to insure accuracy, such as those described in the Code of the Committee of the American Society of Mechanical Engineers,* (see abstract below). Experts in boiler-testing should be employed, and the water fed to the boiler should be weighed, or measured in calibrated tanks,

* Trans. A.S.M.E., 1915, Reprinted in pamphlet form by the Society. The first committee of the society on boiler-tests reported in 1885, the second in 1899. In 1909 a committee on Tests of Power Plant Apparatus was appointed; its preliminary report was published in 1912, and its final report in 1915. The author was chairman of the first committee and member of the other two.

and not by a water-meter, which is apt not only to have an error at its average rate of running, but also an error which varies with every change in the rate. For the other three purposes, however, water-meters, if calibrated before and after the test by means of running water through them, at the average rate and pressure used in the test, into a tank set on a platform scale, are sufficiently accurate, and the regular engineering force of the establishment should be capable of making the test.

In large plants, in which the yearly cost of coal amounts to some thousands of dollars, there are apt to be wastes of fuel, amounting to as much as 10 or 20 per cent of the total consumption, which are unsuspected until they are discovered by a series of tests. When several boilers discharge their gases into the same flue leading to the chimney, unless the draft conditions at each boiler are carefully equalized, one or more of the boilers is likely to be running under unfavorable draft conditions. If the boilers are of different types or different proportions of grate and heating surface, the draft and the method of firing which are best for one boiler may not be best for another. For these reasons it is important in designing and constructing a large boiler plant to arrange the feed-pipes so that a meter may at any time be placed in the feed-pipe of any one of the boilers, in order that a test of 24 hours, or a week, if desired, may easily be made. It is an easy matter to weigh all the coal used by the boiler during the test, and to keep hourly records of the coal- and water-consumption, the steam pressure, and the temperatures of the feed-water and the waste gases.

Besides the tests of each boiler in a plant, which ought to be made occasionally, say every two or three years, a continuous record of the performance of the plant may be made by having a large meter in the main feed-line, noting the water-consumption daily, weekly or monthly, and comparing it with the monthly coal bills. In electric light and power stations the boiler-record should be compared with the record of the electric current given by the volt and ampere meters.

For all important tests, where the greatest accuracy is essential, the provisions of the Code, the principal parts of which relating to steam boilers are given in condensed form below, should be followed.

Instructions Regarding Tests in General.

(Code of 1915).

OBJECT.

Ascertain the specific object of the test, and keep this in view not only in the work of preparation, but also during the progress of the test.

If questions of fulfillment of contract are involved, there should be a clear understanding between all the parties, preferably in writing, as to the operating conditions which should obtain during the trial, the methods of testing to be followed, corrections to be made in case the conditions actually existing during the test differ from those specified, and all other matters about which dispute may arise, unless these are already expressed in the contract itself.

PREPARATIONS.

Dimensions. Measure the dimensions of the principal parts of the apparatus to be tested, so far as they bear on the objects in view, or determine them from working drawings. Notice the general features of the apparatus, both exterior and interior, and make sketches, if needed, to show unusual points of design.

The areas of the heating surfaces of boilers and superheaters to be found are those of surfaces in contact with the fire or hot gases. The submerged surfaces in boilers at the mean water level should be considered as water-heating surfaces, and other surfaces which are exposed to the gases as superheating surfaces.

Examination of Plant. Make a thorough examination of the physical condition of all parts of the plant or apparatus which concern the object in view, and record the conditions found.

In boilers examine for leakage of tubes and riveted or other metal joints. Note the condition of brick furnaces, grates and baffles. Examine brick walls and cleaning doors for air leaks, either by shutting the damper and observing the escaping smoke or by candle-flame test. Determine the condition of heating surfaces with reference to exterior deposits of soot and interior deposits of mud or scale.

If the object of the test is to determine the highest efficiency or capacity obtainable, any physical defects, or defects of operation, tending to make the result unfavorable should first be remedied; all fouled parts being cleaned, and the whole put in first-class condition. If, on the other hand, the object is to ascertain the performance under existing conditions, no such preparation is either required or desired.

Precautions against Leakage. In steam tests make sure that there is no leakage through blowoffs, drips, etc., or any steam or water connections, which would in any way affect the results.

All such connections should be blanked off, or satisfactory assurance should be obtained that there is leakage neither out nor in.

Apparatus and Instruments. See that the apparatus and instruments are substantially reliable, and arrange them in such a way as to obtain correct data.

Weighing Scales. For determining the weight of coal, oil, water, etc., ordinary platform scales serve every purpose. Too much dependence, however, should not be placed upon their reliability without first calibrating them by the use of standard weights, and carefully examining the knife-edges, bearing plates, and ring suspensions, to see that they are all in good order.

For testing locomotives and some classes of marine boilers, where room is lacking, sacks or bags are sometimes required to facilitate the handling of coal, the weighing being done before loading on the tender or delivery to the fire room.

Water Weighing and Measuring Apparatus. Wherever practicable the feedwater should be weighed, especially for guarantee tests. The most satisfactory and reliable apparatus for this purpose consists of one or more tanks each placed on platform scales, these being elevated a sufficient distance above the floor to empty into a receiving tank placed below, the latter being connected to the feed pump. Measuring tanks calibrated by weighing may also be used.

In tests of complete steam power plants, where it is required to measure the feedwater without unnecessary change in the working conditions, a water meter may be employed. Meter measurement may also be required in many other cases, such as locomotive and marine service. The accuracy of meters should be determined by calibration in place under the conditions of use.

If a large quantity of water is to be measured, an automatic water-weigher, a rotary, disk, or Venturi meter, a weir, or some form of orifice measurement may be employed. The measuring apparatus should be calibrated under the conditions of use, unless its design is such that standard formulæ and constants may be applied for determining the discharge. If recording mechanism is employed in connection with orifice or weir measuring apparatus, make sure that its record is reliable.

Steam Measuring Apparatus. Various forms of steam meters may be employed for measuring steam, provided such meters are properly calibrated under conditions of use, and the pulsations of pressure, if any, are not serious.

Pressure Gages. For determining pressure the gages belonging to the plant may be used, provided they are compared with a standardized gage of the spring or mercury type and verified, due allowance being made for the head of water, if any, standing in the connecting pipe. Such comparisons should be made with both gages at their respective normal temperatures. In the use of spring gages for steam the gages should be protected by proper syphons or water seals and no leakage should be allowed at the gage-cock. The gages should also be located so that they will not be unduly heated.

Thermometers. Thermometers should be of the kind having graduations marked on the glass stem. Those used for temperatures above the boiling point of mercury (or say above 500° F.) should have nitrogen in the top of the bore. They should also have a small safety bulb at the top. Thermometers constructed in this way can be used satisfactorily up to 1000° F.

Thermometers which are used for important data should be calibrated before and after a test, by reference to standard thermometers.

Pyrometers. Metallic pyrometers used for determining high temperatures must be handled cautiously owing to the difficulty of exposing the whole of the stem to the current of gas, the temperature of which is to be determined. Electric pyrometers either of the thermo-couple or resistance type are satisfactory for this work within their practical range, which is

1800° F. for iron-nickel couples and 3000° F. for platinum-iridium couples or platinum resistance pyrometers. Instruments of this kind can readily be calibrated by comparing them at low ranges of temperature with a standardized mercurial thermometer, both being placed for example in a current of hot air the temperature of which is under control. For extremely high temperatures such as that of a boiler furnace, the optical, pneumatic, and radiation pyrometers may be used. The calibration of high-temperature instruments can best be undertaken in a laboratory especially fitted for the purpose.

Draft Gages. When the ordinary U-tube is kept clean and the two legs are close together with the scale extending at least to the center of each leg, it gives satisfactory indications. For measuring small amounts of draft some form of multiplying gage may be employed, such as a U-tube in which one leg is inclined from the horizontal, the multiplication varying inversely as the sine of the angle of inclination, the tube being filled with a light mineral oil. These can be calibrated by comparison with the simple U-tube gage when indicating a high-draft, say one inch or more. It is preferable to use kerosene instead of water in the U-tube, and make allowance for the difference of specific gravity. Draft readings should be expressed in inches of water-column.

Steam Calorimeters. The most satisfactory instruments for determining the amount of moisture in steam are calorimeters that operate upon the throttling principle, or that combine the throttling and separating principles; the orifice used being of such size as to throttle to atmospheric pressure, and the instrument being provided with two thermometers, one showing the temperature above the orifice and the other that below it. Instruments working on the separating principle alone may also be employed; also certain forms of electric calorimeters.

Fuel Calorimeters. To determine the total heat of combustion of a sample of coal or other fuel, the best form of calorimeter is one in which the fuel is burned in an atmosphere of oxygen gas. The Mahler type of calorimeter is recognized as the most complete and accurate apparatus of this kind. The total heat of combustion of gas should be found by burning the gas in the Junker calorimeter.

Smoke Determination. No wholly satisfactory methods for smoke determinations have yet come into use, nor have any reliable methods been established for definitely fixing even the relative density of the smoke issuing from chimneys at different times. One method commonly employed which answers the purpose fairly well, is that of making frequent visual observations of the chimney at intervals of one minute or less for a period of one hour and recording the observed characteristics according to the degree of blackness and density, and giving to the various degrees of smoke an arbitrary percentage value rated in some such manner as that expressed in the following table:

SMOKE PERCENTAGES

Dense black	100
Medium black	80
Dense gray	60
Medium gray	40
Light gray	20
Very light	5
Trace	1
Clear chimney	0

The color and density of smoke depend somewhat on the character of the sky or other background, and on the air and weather conditions obtaining when the observation is made, and these should be given due consideration in making comparisons. Observations of this kind are also

subject to personal errors and errors of judgment. Nevertheless, these methods are useful, especially when the results are plotted, according to the percentage scale determined on, so that a graphic representation of the changes can be shown.

SAMPLING AND DRYING COAL

Select a representative shovelful from each barrow-load as it is drawn from the coal pile or other source of supply, and store the samples in a cool place in a covered metal receptacle. When all the coal has thus been sampled, break up the lumps, thoroughly mx the whole quantity, and finally reduce it by the process of reipeated quartering and crushing to a sample weighing about 5 lb., the largest pieces being about the size of a pea. From this sample two 1-qt. air-tight glass fruit jars, or other air-tight vessels, are to be promptly filled and preserved for subsequent determinations of moisture, calorific value, and chemical composition.

When the sample lot of coal has been reduced by quartering to say 100 lb., a portion weighing say 15 to 20 lb. should be withdrawn for the purpose of immediate moisture determination. This is placed in a shallow iron pan and dried on the hot iron boiler flue for at least 12 hours, being weighed before and after drying on scales reading to quarter ounces.

The moisture thus determined is approximately reliable for anthracite and semi-bituminous coals, but not for coals containing much inherent moisture. For such coals, and for all reliable determinations the method to be pursued is as follows:

Take one of the samples contained in the glass jars, and subject it to a thorough air drying, by spreading it in a thin layer and exposing it for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill or other suitable crusher adjusted so as to produce somewhat coarse grains (less than $\frac{1}{16}$ in.), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams (say $\frac{1}{2}$ oz. to 2 oz), weigh it in a balance which will easily show a variation as small as 1 part in 1000, and dry it for one hour in an air or sand bath at a temperature between 240 and 280° F. Weigh it and record the loss, then heat and weigh again until the minimum weight has been reached. The difference between the original and the minimum weight is the moisture in the air-dried coal. The sum of the moisture thus found and that of the surface moisture is the total moisture.

If a large drying oven is available the moisture may be determined by heating one of the glass jars full of coal, the cover being removed, at a temperature between 240° and 280° F. until it reaches the minimum weight.

With certain lignites lower temperatures for drying may be advisable.

SAMPLING ASHES AND REFUSE.

The general method above described may also be followed for obtaining a sample of the ashes and refuse, and for determining the amount of moisture, if any, in the sample.

SAMPLING STEAM.

Construct a sampling pipe or nozzle made of ½-in. iron pipe and insert it in the steam main at a point where the entrained moisture is likely to be most thoroughly mixed. The inner end of the pipe, which should extend nearly across to the opposite side of the main, should be closed and the interior portion perforated with not less than twenty ⅛-in. holes equally distributed from end to end and

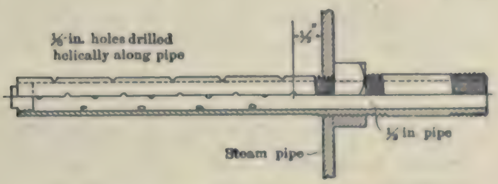

FIG. 244.—PIPE FOR SAMPLING STEAM.

preferably drilled in irregular or spiral rows, with the first hole not less than half an inch from the wall of the pipe. (See Fig. 244.)

The sampling pipe should not be placed near a point where water may pocket or where such water may effect the amount of moisture contained in the sample.

PROXIMATE ANALYSIS OF AIR-DRIED COAL.

To determine volatile matter place about one gram of the air-dried powdered coal in the crucible and heat it in a drying oven to 220° F. for one hour (or longer if necessary to obtain the minimum weight), cool in a dessicator and weigh. Cover the crucible with a loose platinum plate. Heat 7 minutes with a Bunsen burner giving a 6 to 8-in. flame, the crucible being supported 3 in. above the top of the burner tube and protected from outside air currents by a cylindrical asbestos chimney 3 in. diameter. Cool in a dessicator, remove the cover and weigh. The loss in weight represents the volatile matter.

To ascertain the ash, heat the residue in the crucible by a blast lamp until it is completely burned, using a stream of oxygen if desired to hasten the process. The residue is the ash.

The difference between the residue left after the expulsion of the volatile matter and the ash is the fixed carbon.

SAMPLING FLUE GASES.

The sample for flue gas analysis should be drawn from the region near the center of the main body of escaping gases, using a sampling pipe not larger than ¼-in. gas pipe. The point selected should be one where there is no chance for air-leakage into the flue which

could affect the average quality. In a round or square flue having an area of nor more than one-eighth of the grate surface, the sampling pipe may be introduced horizontally at a central line, or preferably a little higher than this line, and the pipe should contain perforations extending the whole length of the part immersed, pointing toward the current of gas, the collective area of the perforations being less than the area of the pipe. The pipe should be frequently removed and cleaned.

It is advisable to take samples both from the flue and from the furnace, so as to determine the amount of air leakage through the setting and the changes in the composition of the gas between the furnace and the flue.

It is best to draw a continuous sample, using a suitable aspirator, and provide a branch pipe from which to obtain the test-sample. The test sample can then be taken either momentarily or continuously, according to the requirements.

MISCELLANEOUS INSTRUCTIONS.

The person in charge of a test should have the aid of a sufficient number of assistants, so that he may be free to give special attention to any part of the work whenever and wherever it may be required. He should make sure that the instruments and testing apparatus continually give reliable indications, and that the readings are correctly recorded. He should also keep in view, at all points, the operation of the plant or part of the plant under test and see that the operating conditions determined on are maintained and that nothing occurs, either by accident or design, to vitiate the data. This last precaution is especially needed in guarantee tests.

Before a test is undertaken, it is important that the boiler, engine, or other apparatus concerned shall have been in operation a sufficient length of time to attain working temperatures and proper operating conditions throughout, so that the results of the test may express the true working performance.

It would, for example, be manifestly improper to start a test for determining the maximum efficiency of an externally fired boiler with brick setting, until the boiler had been at work a sufficient number of days to dry out thoroughly and heat the brick work to its working temperature.

An exception should be noted where the object of the test is to obtain the working performance, including the effect of preliminary heating, in which case all the conditions should conform to those of regular service.

In preparation for a test to demonstrate maximum efficiency, it is desirable to run preliminary tests for the purpose of determining the most advantageous conditions.

OPERATING CONDITIONS.

In all tests in which the object is to determine the performance under conditions of maximum efficiency, or where it is desired to ascertain the effect of predetermined conditions of operation, all such conditions which have an appreciable effect upon the efficiency should be maintained as nearly uniform during the trial as the limitations of practical work will permit. Where maximum efficiency is the object in view, there should be uniformity in such matters as steam pressure, times of firing, quantity of coal supplied at each firing, thickness of fire, and in other firing operations; also in the rate of supplying the feedwater, in the load, and in the operating conditions throughout. On the other hand, if the object of the test is to determine the performance under working conditions, no attempt at uniformity is either desired or required unless this uniformity corresponds to the regular practice, and when this is the object the usual working conditions should prevail throughout the trial.

RECORDS.

A log of the data should be entered in notebooks or on blank sheets suitably prepared in advance. This should be done in such manner that the test may be divided into hourly periods, or if necessary, periods of less duration, and the leading data obtained for any one or more periods as desired, thereby showing the degree of uniformity obtained.

The readings of instruments and apparatus concerned in the test other than those showing quantities of consumption (such as fuel, water, and gas), should be taken at intervals not exceeding half an hour and entered in the log. When the indications fluctuate, the intervals should be reduced. In the case of smoke observations it is often necessary to take observations every minute, or still oftener.

Make a memorandum of every event connected with the progress of a test, however unnecessary at the time it may appear. A record should be made of the exact time of every such occurrence and the time of taking every weight and every observation. For the purpose of identification the signature of the observer and the date should be affixed to each log sheet or record.

In the simple matter of weighing coal by the barrow-load, or weighing water by the tank-full, which is required in many tests, a series of marks, or tallies, should never be trusted. The time each load is weighed or emptied should be recorded. The weighing of coal should not be delegated to unreliable assistants, and whenever practicable, one or more men should be assigned solely to this work. The same may be said with regard to the weighing of feedwater.

PLOTTING DATA AND RESULTS.

If it is desired to show the uniformity of the data at a glance the whole log of the trial should be plotted on a chart, preferably while the test is in progress, using horizontal distances to represent times of observation, and vertical distances on suitable scales to represent various data as recorded.

REPORT.

The report of a test should present all the leading facts bearing on the design, dimensions, condition, and operation of the apparatus tested, and should include a description of any other apparatus and auxiliaries concerned, together with such sketches as may be needed for a clear understanding of all points under consideration. It should state clearly the object and character of the test, the methods followed, the conditions maintained, and the conclusions reached, closing with a tabular summary of the principal data and results.

Rules for Conducting Evaporative Tests of Boilers

OBJECT AND PREPARATIONS.

Determine the object of the test, take the dimensions, note the physical conditions, examine for leakages, install the testing appliances, etc., as pointed out in the general instructions and make preparations for the test accordingly.

FUEL.

Determine the character of fuel to be used. For tests of maximum efficiency or capacity of the boiler to compare with other boilers, the coal should be of some kind which is commercially regarded as a standard for the locality where the test is made.

A coal selected for maximum efficiency and capacity tests should be the best of its class, and especially free from slagging and unusual clinker-forming impurities.

For guarantee and other tests with a specified coal containing not more than a certain amount of ash and moisture, the coal selected should not be higher in ash and in moisture than the stated amounts because any increase is liable to reduce the efficiency and capacity more than the equivalent proportion of such increase.

OPERATING CONDITIONS.

Determine what the operating conditions and method of firing should be to conform to the object in view, and see that they prevail throughout the trial, as nearly as possible.

Where uniformity in the rate of evaporation is required, arrangement can usually be made to dispose of the steam so that this result can be attained. In a single boiler it may be accomplished by discharging steam through a waste pipe and regulating the amount by means of a valve. In a battery of boilers, in which only one is tested, the draft may be regulated on the remaining boilers to meet the varying demands for steam, leaving the test boiler to work under a steady rate of evaporation.

DURATION.

The duration of tests to determine the efficiency of a hand-fired boiler, should be at least 10 hours of continuous running, or such time as may be required to burn a total of 250 lb. of coal per square foot of grate.

In the case of a boiler using a mechanical stoker, the duration, where practicable, should be at least 24 hours. If the stoker is of a type that permits the quantity and condition of the fuel bed at beginning and end of the test to be accurately estimated, the duration may be reduced to 10 hours, or such time as may be required to burn the total of 250 lb. per. sq. ft.

In commercial tests where the service requires continuous operation night and day, with frequent shifts of firemen, the duration of the test, whether the boilers are hand-fired or stoker-fired, should be at least twenty-four hours.

STARTING AND STOPPING.

The conditions regarding the temperature of the furnace and boiler, the quantity and quality of the live coal and ash on the grates, the water level, and the steam pressure, should be as nearly as possible the same at the end as at the beginning of the test.

To secure the desired equality of conditions with hand-fired boilers, the following method should be employed:

The furnace being well heated by a preliminary run, burn the fire low, and thoroughly clean it, leaving enough live coal spread evenly over the grate (say 2 to 4 ins.),* to serve as a foundation for the new fire. Note quickly the thickness of the coal bed as nearly as it can be estimated or measured; also the water level,† the steam pressure, and the time, and record the latter as the starting time. Fresh coal should then be fired from that weighed for the test, the ashpit thoroughly cleaned, and the regular work of the test proceeded with.

Before the end of the test the fire should again be burned low and cleaned in such a manner as to leave the same amount of live coal on the grate as at the start. When this condition is reached, observe quickly the water level,† the steam pressure, and the time, and record the latter as the stopping time. If the water level is lower than at the beginning, a correction should be made by computation, rather than by feeding additional water. Finally remove the ashes and refuse from the ashpit.

In a plant containing several boilers where it is not practicable to clean them simultaneously, the fires should be cleaned one after the other as rapidly as may be, and each one after cleaning charged with enough coal to main-

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* 1 to 2 in. for small anthracite coals.

† Do not blow down the water-glass column for at least one hour before these readings are taken. An erroneous indication may otherwise be caused by a change of temperature and density of the water within the column and connecting pipe.

tain a thin fire in good working condition. After the last fire is cleaned and in working condition, burn all the fires low (say 4 to 6 in.), note quickly the thickness of each, also the water levels, steam pressure, and time, which last is taken as the starting time. Likewise when the time arrives for closing the test, the fires should be quickly cleaned one by one, and when this work is completed they should all be burned low the same as at the start and the various observations made as noted.

In the case of a large boiler having several furnace doors requiring the fire to be cleaned in sections one after the other, the above directions pertaining to starting and stopping in a plant of several boilers may be followed.

To obtain the desired equality of conditions of the fire when a mechanical stoker other than a chain grate is used, the procedure should be modified where practicable as follows:

Regulate the coal feed so as to burn the fire to the low condition required for cleaning. Shut off the coal-feeding mechanism and fill the hoppers level full. Clean the ash or dump plate, note quickly the depth and condition of the coal on the grate, the water level, the steam pressure, and the time, and record the latter as the starting time. Then start the coal-feeding mechanism, clean the ashpit, and proceed with the regular work of the test.

When the time arrives for the close of the test, shut off the coal-feeding mechanism, fill the hoppers and burn the fire to the same low point as at the beginning. When this condition is reached, note the water level, the steam pressure, and the time, and record the latter as the stopping time. Finally clean the ash plate and haul the ashes.

In the case of chain grate stokers, the desired operating conditions should be maintained for half an hour before starting a test and for a like period before its close, the height of the stoker gate or throat plate and the speed of the grate being the same during both of these periods.

RECORDS.

Half-hourly readings of the instruments are usually sufficient. If there are sudden and wide fluctuations, the readings in such cases should be taken every fifteen minutes, and in some instances oftener.

In hand-fired tests the coal should be weighed and delivered to the firemen in portions sufficient for one hour's run, thereby ascertaining the degree of uniformity of firing. An ample supply of coal should be maintained at all times, but the quantity on the floor at the end of each hour should be as small as practicable, so that the same may be readily estimated and deducted from the total weight. Likewise in stoker tests the weight of coal fed to the furnace each hour should be determined.

The records should be such as to ascertain also the consumption of feedwater each hour, and thereby determine the degree of uniformity of evaporation.

QUALITY OF STEAM.

If the boiler does not produce superheated steam the percentage of moisture in the steam should be determined by the use of a throttling or separating calorimeter. If the boiler has superheating surface, the temperature of the steam should be determined by the

use of a thermometer inserted in a thermometer well in the steam-pipe.

SAMPLING AND DRYING COAL.

During the progress of the test the coal should be regularly sampled for the purpose of analysis and determination of moisture.

ASHES AND REFUSE.

The ashes and refuse withdrawn from the furnace and ash-pit during the progress of the test and at its close should be weighed so far as possible in a dry state. If wet the amount of moisture should be ascertained and allowed for, a sample being taken and dried for this purpose. This sample may serve also for analysis for the determination of unburned carbon.

CALORIFIC TESTS AND ANALYSES OF COAL.

The quality of the fuel should be determined by calorific tests and analyses of the coal sample above referred to.

ANALYSES OF FLUE GASES.

For approximate determinations of the composition of the flue gases, the Orsat apparatus, or some modification thereof, should be employed. If momentary samples are obtained the analyses should be made as frequently as possible, say every 15 to 30 minutes, depending on the skill of the operator, noting at the time the sample is drawn the furnace and firing conditions. If the sample drawn is a continuous one, the intervals may be made longer.

SMOKE OBSERVATIONS.

In tests of bituminous coals requiring a determination of the amount of smoke produced, observations should be made regularly throughout the trial at intervals of five minutes (or if necessary every minute), noting at the same time the furnace and firing conditions.

For observations covering a period of one or more single firings, the intervals should be quarter minutes.

CALCULATION OF RESULTS.

(*a*) *Corrections for Quality of Steam.* When the percentage of moisture is less than 2 per cent it is sufficient merely to deduct the percentage from the weight of water fed, in which case the factor of correction for quality is

$$1-\frac{\%\text{ moisture}}{100}.$$

When the percentage is greater than 2 per cent, or if extreme accuracy is required, the factor of correction is

$$1-P\frac{H-h_1}{H-h},$$

in which P is the proportion of moisture, H the total heat of 1 lb. of saturated steam, h_1 the heat in water at the temperature of saturated steam, and h the heat in water at the feed temperature.

When the steam is superheated the factor of correction for quality of steam is

$$\frac{H_s-h}{H-h},$$

in which H_s is the total heat of 1 lb. of superheated steam of the observed temperature and pressure.

Unless otherwise provided, a combined boiler and superheater should be treated as one unit, and the equivalent of the work done by the superheater should be included in the evaporative work of the boiler.

(*b*) *Correction for Steam or Power used for Aiding Combustion.* The quantity of steam or power, if any, used for producing draft, injecting fuel, or aiding combustion, should be determined and recorded in the Table of Data and Results. There should also be recorded, by foot-note below the table, a statement showing whether or not a deduction has been made from the total evaporation for steam or power used, and if such deduction has been made, the method of computing it.

(*c*) *Equivalent Evaporation.* The equivalent evaporation from and at 212° is obtained by multiplying the weight of water evaporated, corrected for moisture in steam, by the "factor of evaporation." The latter equals

$$\frac{H-h}{970.4},$$

in which H and h are respectively the total heat of saturated steam and of the feedwater entering the boiler.

The "factor of evaporation" and the "factor of correction for quality of steam" may be combined into one expression in the case of superheated steam as follows:

$$\frac{H_s-h}{970.4}.$$

(*d*) *Efficiency.* The "efficiency of boiler, furnace and grate" is the relation between the heat absorbed per pound of coal as fired, and the calorific value of 1 lb. of coal as fired.

The "efficiency based on combustible" is the relation between the heat absorbed per pound of combustible burned and the calorific value of 1 lb. of combustible. This expression of efficiency furnishes an approximate means for comparing the results of different tests when the losses of unburned coal due to grates, cleanings, etc., are eliminated.

The "combustible burned" is determined by subtracting from the weight of coal supplied to the boiler, the moisture in the coal, the weight of ash and unburned coal withdrawn from the furnace and ashpit, and the weight of dust, soot, and refuse, if any, withdrawn from the tubes, flues, and combustion chambers, including ash carried away in the gases, if any, determined from the analyses of coal and ash.* The "combustible" used for determining the calorific value is the weight of coal less the moisture and ash found by analysis.

*In cases of high rates of combustion the determination of the combustible burned may be subject to considerable error on account of the loss of cinders, soot and unburned fuel which are blown to waste.

The "heat absorbed" per pound of coal or combustible is calculated by multiplying the equivalent evaporation from and at 212° per pound of coal or combustible by 970.4.

(*e*) *Heat Balance.* A "heat balance," or approximate distribution of the calorific value of 1 lb. of dry coal among the several items of heat utilized and heat lost, should be obtained in cases where the flue gases have been analyzed and a complete analysis made of the coal.

The loss due to moisture in the coal is found by multiplying the total heat of 1 lb. of superheated steam at the temperature of the escaping gases, calculated from the temperature of the air in the boiler room, by the proportion of moisture, referred to dry coal.

The loss due to moisture formed by the burning of hydrogen is obtained by multiplying the total heat of 1 lb. of superheated steam at the temperature of the escaping gases, calculated from the temperature of the air in the boiler room, by the proportion of the hydrogen, determined from the analysis of the coal, referred to dry coal, and multiplying the result by 9.

The loss due to heat carried away in the dry gases is found by multiplying the weight of gas per pound of dry coal by the elevation of temperature of the gases above the temperature of the boiler room, and by the specific heat of the gases (0.24). The weight of gas per lb. of dry coal is obtained by finding the weight of dry gas per pound of carbon burned, using the formula

$$\frac{11\,CO_2+8O+7(CO+N)}{3(CO_2+CO)},$$

in which CO_2, CO, O, and N are expressed in percentages by volume, and multiplying this result by the proportion borne by the carbon burned to the whole amount of dry coal as determined from the results of the analysis of the coal, ash, and refuse.

The loss due to incomplete combustion of carbon is found by first obtaining the proportion borne by the carbon monoxide in the gases to the sum of the carbon monoxide and carbon dioxide, and then multiplying this proportion by the proportion of carbon in the coal minus the carbon lost in the ash and refuse, and finally multiplying the product by 10,150, which is the number of heat units generated by burning to carbon dioxide one pound of carbon contained in carbon monoxide.

The loss due to combustible matter in the ash and refuse is found by multiplying the proportion that this combustible bears to the whole amount of dry coal by its calorific value per pound. For most purposes it is sufficient to assume the latter to be 14,600 B.T.U., the same as that of carbon.

The loss due to moisture in the air is determined by multiplying the weight of such moisture per pound of dry coal by the elevation of temperature of the flue gases above the temperature of the boiler room and by 0.47. The weight of moisture is found by multiplying the weight of air per pound of dry coal by the moisture in one pound of air determined from readings of the wet and dry-bulb thermometer.

(*f*) *Total Heat of Combustion of Coal, by Analysis.* The total heat of combustion may be computed from the results of the ultimate analysis by using the formula

$$14{,}600\,C+62{,}000\left(H-\frac{O}{8}\right)+4000\,S,$$

in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur, respectively.

(*g*) *Air for Combustion.* The quantity of air used may be calculated by the formulæ:

$$\text{Lb. of air per lb. of carbon}=\frac{3.032\,N}{CO_2+CO},$$

in which N, CO_2 and CO are the percentages of dry gas obtained by analysis and

Lb. of air per lb. of coal = lb. air per lb. C × (per cent C in the coal, less per cent carbon in refuse, referred to coal).

The ratio of the air supply to that theoretically required for complete combustion is $\frac{N}{N-3.782(O-\frac{1}{2}CO)}$.

DATA AND RESULTS.

The data and results should be reported in accordance with the form printed below, adding lines for data not provided for, or omitting those not required, as may conform to the object in view.

CHART.

In trials having for an object the determination and exposition of the complete boiler performance, the entire log of readings and data should be plotted on a chart and represented graphically.

TESTS WITH OIL AND GAS FUELS.

Tests of boilers using oil or gas for fuel should accord with the rules here given, excepting as they are varied to conform to the particular characteristics of the fuel. The proper length of tests with gas and oil fuels may be determined by a consideration of the probable errors and the degree of accuracy desired, the minimum duration for economy tests being 5 hours. With these fuels the "flying" method of starting and stopping is employed.

The table of data and results should contain items stating character of furnace and burner, quality and composition of oil or gas, temperature of oil, and data regarding the performance of the apparatus supplying the fuel.

DATA AND RESULTS OF EVAPORATIVE TEST.*

1. Test of . . To determine . . . . Test conducted by . . boiler located at . .	
2. Number and kind of boilers	
3. Kind of furnace	
4. Grate surface (width . . . . length . . . .)	Sq. ft.
5. Water heating surface	"
6. Superheating surface	"
7. Total heating surface	"
d. Volume of combustion space between grate and heating surface	"
e. Distance from center of grate to nearest heating surface	ft.

Date, Duration, etc.

8. Date	
9. Duration	Hrs.
10. Kind and size of coal	

* This table contains the principal items of the table in the Code of 1915 of the A.S.M.E Committee on Power Tests.

Average Pressures, Temperatures, etc.

11. Steam pressure by gage	Lbs.
12. Temperature of steam, if superheated	Deg.
13. Temperature of feed water entering boiler	"
14. Temperature of escaping gases leaving boiler	"
15. Force of draft between damper and boiler	In.
c. Draft in furnace	"
d. Draft or blast in ash pit	"
16. State of weather	
a. Temperature of external air	Deg.
b. Temperature of air entering ash pit	"
c. Relative humidity of air entering ash pit	"

Quality of Steam.

17. Percentage of moisture in steam or degrees of superheating	Per cent or deg.
18. Factor of correction for quality of steam	"

Total Quantities.

19. Total weight of coal as fired *	Lbs.
20. Percentage of moisture in coal as fired	Per cent
21. Total weight of dry coal fired	Lbs.
22. Total ash, clinkers, and refuse (dry)†	"
23. Total combustible burned (Item 21 − Item 22)	"
24. Percentage of ash and refuse in dry coal	Per cent
25. Total weight of water fed to boiler ‡	Lbs.
26. Total water evaporated, corrected for quality of steam (Item 25 × Item 18)	Lbs.
27. Factor of evaporation based on temperature of water entering boiler.	
28. Total equivalent evaporation from and at 212° (Item 26 × Item 27)	Lbs.

Hourly Quantities and Rates.

29. Dry coal per hour	Lbs.
30. Dry coal per square foot of grate surface per hour	"
31. Water evaporated per hour, corrected for quality of steam	"
32. Equivalent evaporation per hour from and at 212° §	"
33. Equivalent evaporation per hour from and at 212° per square foot of water heating surface*	"

Capacity.

34. Evaporation per hour from and at 212° (same as Item 32)	Lbs.
a. Boiler horsepower developed (Item 34 ÷ 34½)	Bl. H.P.
35. Rated capacity per hour, from and at 212°	Lbs.
a. Rated boiler horsepower	Bl. H.P.
36. Percentage of rated capacity developed	Per cent

Economy.

37. Water fed per pound of coal as fired (Item 25 ÷ Item 19)	Lbs.
38. Water evaporated per pound of dry coal (Item 26 ÷ Item 21)	"

* The term "as fired" means actual conditions including moisture. Weight corrected fo estimated difference in weight of coal on the grate at beginning and end.

† Corrected when practicable for dust, soot, etc.

‡ Corrected for inequality of water level and of steam pressure at beginning and end.

§ The symbol "U. E." meaning Units of Evaporation, may be substituted for the expression, Equivalent evaporation from and at 212°.

39. Equivalent evaporation from and at 212° per pound of coal as fired (Item 28 ÷ Item 19) .... "
40. Equivalent evaporation from and at 212° per pound of dry coal (Item 28 ÷ Item 21) .... "
41. Equivalent evaporation from and at 212° per pound of combustible (Item 28 ÷ Item 23).. "

Efficiency.

42. Calorific value of 1 lb. of dry coal by calorimeter *.............. B.T.U.
 a. Calorific value of 1 lb. dry coal by analysis................ "
43. Calorific value of 1 lb. of combustible by calorimeter............ "
 a. Calorific value of 1 lb. combustible by analysis............. "
44. Efficiency of boiler, furnace and grate,

$$100 \times \frac{\text{Item } 40 \times 970.4}{\text{Item } 42}.$$

45. Efficiency based on combustible.

$$100 \times \frac{\text{Item } 41 \times 970.4}{\text{Item } 43}.$$

Cost of Evaporation.

46. Cost of coal per ton of .... lbs. delivered in boiler room......... Dollars
47. Cost of coal required for evaporation 1000 lbs. of water under observed conditions.. "
48. Cost of coal required for evaporating 1000 lbs. of water from and at 212°.. "

Smoke Data.

49. Percentage of smoke as observed............................. Per cent

Firing Data.

50. Kind of firing, whether spreading, alternate, or coking...........
 c. Average interval between times of leveling or breaking up... Min.
51. Analysis of dry gases by volume:
 a. Carbon dioxide (CO_2).. Per cent
 b. Oxygen (O).. "
 c. Carbon monoxide (CO)...................................... "
 d. Hydrogen and hydrocarbons.................................. "
 e. Nitrogen, by difference (N)................................. "
52. Proximate analysis of coal

	As Fired.	Dry Coal.	Combustible.
a. Moisture		——	——
b. Volatile matter			
c. Fixed carbon			
d. Ash			——
	100%	100%	100%

 e. Sulphur, separately determined............................

* If the calorific value is desired per lb. of coal "as fired," multiply by 100 – Item 20) ÷ 100.

53. Ultimate analysis of dry coal.	
a. Carbon (C)	Per cent
b. Hydrogen (H)	"
c. Oxygen (O)	"
d. Nitrogen (N)	"
e. Sulphur (S)	"
f. Ash	"

54. Analysis of Ash and Refuse, etc.

	Dry Coal.	
	B.T.U.	%
55. Heat balance, based on dry coal and combustible		
a. Heat absorbed by the boiler (Item 40 or 41 × 970.4)		
b. Loss due to evaporation of moisture in coal		
c. Loss due to heat carried away by steam formed by the burning of hydrogen		
d. Loss due to heat carried away in the dry flue gases		
e. Loss due to carbon monoxide		
f. Loss due to combustible in ash and refuse		
g. Loss due to heating moisture in air		
h. Loss due to unconsumed hydrogen and hydrocarbons, to radiation, and unaccounted for		
i. Total calorific value of 1 lb. of dry coal. (Item 42.)		100

If it is desired that the heat balance be based on coal "as fired," or on "combustible burned," the items in the first column are multiplied by the proportion (100 − Item 20) ÷ 100 for coal "as fired," or by 100 ÷ (100 − Item 55*f*, per cent) for "combustible."

Principal Data and Results of Boiler Test.

1. Grate surface (width........ length........)	Sq.ft
2. Total heating surface	"
3. Date	
4. Duration	Hrs.
5. Kind and size of coal	
6. Steam pressure by gage	Lbs.
7. Temperature of feed water entering boiler	Deg.
8. Percentage of moisture in steam or number of degrees of superheating	Per cent or deg.
9. Percentage of moisture in coal	Per cent
10. Dry coal per hour	Lbs.
11. Dry coal per square foot of grate surface per hour	"
12. Equivalent evaporation per hour from and at 212°	"
13. Equivalent evaporation per hour from and at 212° per square foot of heating surface	"
14. Rated capacity per hour, from and at 212°	"
15. Percentage of rated capacity developed	Per cent
16. Equivalent evaporation from and at 212° per pound of dry coal	Lbs.
17. Equivalent evaporation from and at 212° per pound of combustible	"

18. Calorific value of 1 lb. of dry coal by calorimeter.............. B.T.U.
19. Calorific value of 1 lb. of combustible by calorimeter........... "
20. Efficiency of boiler, furnace, and grate

$$100\times\frac{\text{Item }16\times 970.4}{\text{Item }18}. \qquad \text{Per cent}$$

21. Efficiency based on combustible

$$100\times\frac{\text{Item }17\times 970.4}{\text{Item }19}. \qquad \text{Per cent}$$

LOCATION OF INSTRUMENTS FOR BOILER TESTS.*

The feedwater thermometer should be placed in a thermometer well and inserted in the feed pipe. Where an injector is employed, and the water is weighed or measured before it is supplied thereto, the well should be placed on the suction side of the injector, and the injector should receive steam through a short covered pipe connected directly to the boiler under test. If the steam is taken from some other source and it is of different pressure and different quality from that of the boiler under test, correction should be made for such difference. When the temperature of the water changes between the injector and boiler, as by the use of a heater or by excessive radiation, the temperature at which the water enters and leaves the injector and that at which it enters the boiler should all be taken. In that case, the weight to be used is that of the water leaving the injector, computed from the heat units if not directly measured, and the temperature that of the water entering the boiler. The weight of condensed steam to be added to the weight of water entering the injector, to obtain that leaving the injector, may be computed by multiplying the weight entering by the proportion

$$\frac{h_3-h_1}{h_2-h_3},$$

in which

h_1 = heat units per lb. of water entering injector;
h_2 = heat units per lb. of steam entering injector;
h_3 = heat units per lb. of water leaving injector.

The location of the steam calorimeter and steam thermometer should be as close to the boiler as possible.

Draft gages should be attached to each boiler between the hand damper and the boiler, and as near the damper as practicable. In the case of a plant containing a number of boilers, a gage should also be attached to the main flue between the regulating damper and the boiler plant. It is desirable also to have gages connected to the furnace or furnaces of the boilers, and in cases of forced blast, to the ashpits and blower ducts. If there is an economizer in the flue a gage should be connected to the flue at each end of this apparatus. The same draft gage may be used for all the points noted, provided suitable pipes are run from the gage to each, arranged so as to be readily connected to either point at will.

The flue thermometer should be located where it will show the average temperature of the whole body of gas. For an extremely large flue the thermometer may be placed in an oil pot of small diameter, which is suspended in the flue, and the thermometer lifted partially out of the oil when the temperature is read.†

* This and seven following articles are condensed from the Appendix to the Code of 1915

† When electric pyrometers with thermo-couples are used, wires may be run from several couples, located at different points in the boilers or flues, to a single reading instrument, provided with a multiple switch.—W. K.

BITUMINOUS COAL SIZES.

Bituminous coals in the Eastern States may be graded and sized as follows:

(*A*) Run of mine coal; the unscreened coal taken from the mine.

(*B*) Lump coal; that which passes over a bar-screen with openings $1\frac{1}{4}$ in. wide.

(*C*) Nut coal; that which passes through a bar-screen with $1\frac{1}{4}$-in. openings and over one with $\frac{3}{4}$-in. openings.

(*D*) Slack coal; that which passes through a bar-screen with $\frac{3}{4}$-in. openings.

Bituminous coals in the Western States may be graded and sized as follows:

(*E*) Run of mine coal; the unscreened coal taken from the mine.

(*F*) Lump coal; divided into 6-in., 3-in. and $1\frac{1}{4}$ in. lump, according to the diameter of the circular openings over which the respective grades pass; also 6 by 3 lump and 3 by $1\frac{1}{4}$ lump, according as the coal passes through a circular opening having the diameter of the larger figure and over that of the smaller diameter.

(*G*) Nut coal; divided into 3-in. steam nut, which passes through an opening 3-in. diameter and over $1\frac{1}{4}$-in.; $1\frac{1}{4}$-in. nut, which passes through a $1\frac{1}{4}$-in. diameter opening and over a $\frac{3}{4}$-in. diameter opening; $\frac{3}{4}$-in. nut, which passes through a $\frac{3}{4}$-in. diameter opening and over a $\frac{5}{8}$-in. diameter opening.

(*H*) Screenings: that which passes through a $1\frac{1}{4}$-in. diameter opening.

(*I*) Washed sizes; those passing through or over the circular openings of the following diameters, in inches:

Number	Through	Over
1	3	$1\frac{3}{4}$
2	$1\frac{3}{4}$	$1\frac{1}{8}$
3	$1\frac{1}{8}$	$\frac{3}{4}$
4	$\frac{3}{4}$	$\frac{1}{4}$
5	$\frac{1}{4}$	..

WATER GLASS TESTS OF LEAKAGE.

To determine the leakage of steam and water from a boiler and steam pipes, etc., the water-glass method may be satisfactorily employed. This consists of shutting off all the feed valves (which must be known to be tight) and the main feed valve, thereby stopping absolutely the entrance or exit of water at the feed pipes to the boiler; then maintaining the steam pressure (by means of a very slow fire) at a fixed point, which is approximately that of the working pressure, and observing the rate at which the water falls in the gage glasses. It is well, in this test, as in other work of this character, to make observations every ten minutes, and to continue them for such length of time that the differences between successive readings attain a constant rate. It is usually sufficient to continue the test for two hours, thereby obtaining a number of half-hourly periods. The quantity of leakage is ascertained by calculating the volume of water which has disappeared, using the area of the water level and the depth shown on the glass, making due allowance for the weight of one cubic foot of water at the observed pressure. The water columns should not be blown down during the time a water-glass test is going on, nor for a period of at least one hour before it begins.

CALIBRATING WATER METERS.

Referring to Fig. 245, two tees *A* and *B* are placed in the feed pipe, and between them two valves *C* and *D*. The meter is connected between the outlets of the tees *A* and *B* and the valves *E* and *F* are placed one on each side of the meter. When the meter is running, the valves *E* and *F* are opened, and the valves *C* and *D* closed. A small bleeder *G* is kept open to make sure that there is no leakage. A gage is attached at *H*. When the meter is tested, the

valves C, D, and F are closed, and the valves E and I are opened. The water flows from the valve I to a tank on platform scales. In testing the meter, the water is throttled at the valve I to obtain the desired rate of discharge, the gage meanwhile showing the working pressure. The piping leading from the valve I to the tank is arranged with a swinging joint, consisting merely of a loosely fitting elbow, so that it can be readily turned into the tank or away from it. When the desired speed has been secured, the end of the pipe is swung into the tank at the instant the pointer of the meter is opposite some graduation mark on the dial. When the required number of cubic feet are discharged, the pipe is swung away. The tests should start and stop at the same graduation mark on the first dial, and continued until at least 10 or 20 cu. ft. are discharged for one test. The tank is weighed before and after filling.

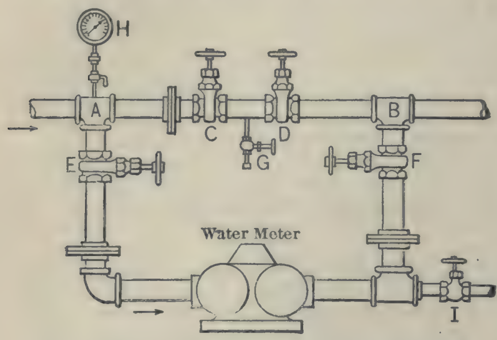

Fig. 245.—Calibrating Water Meters.

The water passing the meter should always be under pressure so that any air in the meter may be discharged through the vents provided for this purpose. Care should be taken that there is no unnecessary air drawn into the feed water. The meter should be tested before and after the trial, and repeated calibrations should be made to obtain confirmative results.

GAS ANALYSIS.

Orsat Apparatus. The Orsat apparatus is a portable instrument contained in a wooden case with removable sliding doors front and back, as shown in its simplest form in Fig. 246. It consists essentially of a measuring tube or burette, three absorbing bottles or pipettes, and a leveling bottle, together with the connecting tubes and apparatus. The bottle and measuring tube contain pure water; the first pipette, sodium or potassium hydrate dissolved in three times its weight of water; the second, pyrogallic acid dissolved in sodium hydrate in the proportion of 5 grams of the acid to 100 c.c. of the hydrate; and the third, cuprous chloride.

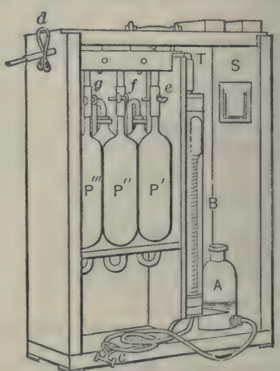

Fig. 246. Orsat Apparatus.

The manipulation of the instrument is as follows:

After completely drawing out the air contained in the supply pipe, a sample of the gas is drawn into the measuring tube by opening the necessary connections and allowing the water to empty itself from the tube and flow into the bottle. The quantity of gas drawn in is adjusted to 100 cc. By opening one by one the connections to the pipettes, and raising and lowering the water bottle, the sample is alternately admitted to and withdrawn from the pipettes, and the ingredients one by one absorbed.

The first pipette absorbs CO_2; the second, O; and the third, CO. The quantity absorbed in each case is determined by returning the sample to the measur-

ing burette and reading the volume. The percentage of CO_2 is read directly being the first absorption. This of the other two ingredients are the respective differences between the readings taken after successive absorptions.

Various modifications of this apparatus have been developed which enable analyses to be made with greater rapidity than with the form illustrated.

Hempel Apparatus. The Hempel apparatus works on the same principle as the Orsat, except that the absorption may be hastened by shaking the pipette bodily, bringing the chemical into most intimate contact with the gas. It is less portable and in some particulars it requires more careful manipulation than the Orsat.

The absorption pipettes are made in sets which are shaped in the form of globes, and a number of independent sets are required for the treatment of the different constituent gases.* A sample pipette of the Hempel type is shown in Fig. 247.

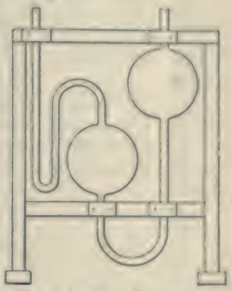

FIG. 247. HEMPEL PIPETTE.

FURNACE EFFICIENCY.

Attempts have been made to separate the combined efficiency of boiler, furnace, and grate into two parts, viz., efficiency due to boiler alone, and efficiency due to furnace (including grate), but there is no agreement as to the exact line of demarcation to be used in separating one from the other.

The heat losses chargeable to the furnace alone are clearly those designated *a*, *b*, *c* and *d* in the following list:

a. The loss due to unburned solid fuel dropping through the grates or withdrawn from the furnace, including the solid combustible matter in the cinders, sparks, flue dust, etc.
b. Loss due to the production of CO instead of CO_2.
c. Loss due to escape of unburned volatile hydrocarbons.
d. Loss due to the combination of carbon and moisture and production of hydrogen (by the reaction $C+H_2O=CO+2H$) when fresh moist coal is thrown on a bed of white hot coke.

The remaining heat losses, which are those due to heat carried away by the air and moisture in the escaping gases, loss from radiation, and losses unaccounted for, may be divided as given below in Items *e* to *j*.

e. Moisture losses; embracing evaporation of moisture and heating of steam thus formed to T_p(T_p = temperature corresponding to boiler pressure).
  1. Moisture in coal.
  2. " air.
  3. " due to burning of hydrogen in the fuel.

f. Moisture losses, consisting in the further heating of steam of Item 3 from T_p to T_g(T_g = temperature of escaping gases).
  1. Moisture in coal.
  2. " air.
  3. " due to H.

g. Theoretical air supply losses.
  1. Heated to T_p.
  2. " from T_p to T_g.

h. Excess air supply losses.
  1. Heated to T_p.
  2. " from T_p to T_g.

* For description of the Hempel apparatus and the method of operating it, see Hempel's Gas Analysis, translated by L. M. Dennis.

i. Radiation.
1. Due to furnace.
2. " boiler.

j. Unaccounted for losses.
1. Due to furnace.
2. " boiler.

It has been suggested that these losses be grouped and apportioned as follows:

U = unavoidable losses $= e_1 + e_2 + e_3 + g_1$;
F = furnace losses $= a + b + c + d + i_1 + j_1$;
B = boiler losses $= f_1 + f_2 + f_3 + g_2 + h_1 + h_2 + i_2 + j_2$;

in which case the individual efficiencies are

$$\text{Maximum theoretical efficiency} = \frac{100 - U}{100};$$

$$\text{Furnace efficiency} = \frac{100 - (U + F)}{100 - U};$$

$$\text{Boiler efficiency} = \frac{100 - (U + F + B)}{100 - (U + F)};$$

$$\text{Combined efficiency of boiler, furnace and grate} = \frac{100 - (U + F + B)}{100}.$$

These formulæ do not however furnish a method of determining the true individual efficiencies desired, because it is impossible to determine Item *d*, and impracticable to obtain Item *c* with the gas-testing appliances ordinarily available. It is impossible also to separate the losses i_1 and j_1 attributed to the furnace, from the boiler losses alone due to radiation and those unaccounted for.

Another suggestion is to transfer the excess air loss h_1 to the group of furnace losses F; but this makes the matter even worse, inasmuch as the furnace efficiency is then dependent on the steam pressure in the boiler, which is a matter foreign to any furnace condition. It further assumes that the flue gases cannot be cooled below the temperature due to the pressure, which although true for many types of boiler, is not true in cases where the contra-flow principle is used.

A third method suggested is to include among the boiler losses all those which have been classed as unavoidable above. By this method the furnace efficiency is

$$\frac{100 - F}{100},$$

and the boiler efficiency

$$\frac{100 - (U + B + F)}{100 - F}.$$

If it is desired to divide the combined efficiency between boiler and furnace in some such manner as those suggested, the method of division employed should be clearly stated.

CALCULATION OF HEAT BALANCE FOR BOILER TEST.

The following example shows the method to be employed in computing the various quantities in the heat balance table.

Data.—Semi-bituminous coal, 2% moisture, 8% ash, 90% combustible, 82% C, 4% H, 3% O, 1% N.

B.T.U. per lb. combustible 15,800; per lb. coal as fired, 14,220. Ash and refuse by boiler test, 13%, referred to coal as fired. The 13% ash and refuse is assumed to contain the 8% of ash shown by the analysis and 5% of combustible.

Efficiency of boiler, furnace, and grate, based on coal as fired, 70%.
The gas analysis shows that 20 lb. of air is supplied per lb. of C burned; and that 0.05 lb. of C was burned to CO, per lb. of carbon burned.
The air is supplied at 92° F., and contains 0.02 lb. of water vapor per lb. of dry air (60% relative humidity). Flue gas temperature 592° F.
Water from and at 212° per lb. coal as fired 10.258; dry coal 10.467; combustible 12.068.

	B.T.U. per Lb.			Combustible.	
	Coal as Fired.	Dry Coal.	Percent.	B.T.U.	Percent.
a. Heat absorbed by the boiler (Item 39, 40 or 41×970.4)	9954	10157	70	11711	74.1
b. Loss due to evaporation of moisture in coal, $0.02 \times [(212-92)+970+.47(592-212)]$	25	26	0.2	29	0.2
c. Loss due to heat carried away by steam formed by the burning of hydrogen $0.04 \times 9 \times (120 \times 970 + 0.47 \times 380)$.	457	466	3.2	538	3.4
d. Loss due to heat carried away in the dry flue gases, 21 lb. per lb. $C = 21 \times 0.77 = 16.17 \times 500 \times 0.24$.	1940	1979	13.7	2282	14.4
e. Loss due to carbon monoxide $0.05 \times 0.77 = .0385$ C per lb. $coal \times 10{,}150$.	391	399	2.7	460	2.9
f. Loss due to combustible in ash and refuse, 0.05×15800	790	806	5.6	. . . .	. . . .
g. Loss due to heating moisture in air, $0.02 \times 20 \times 0.77 \times 500 \times 0.47$.	72	74	0.5	86	0.5
h. Loss due to unconsumed hydrogen and hydrocarbons, to radiation, and unaccounted for.	591	603	4.1	694	4.5
i. Total calorific value of 1 lb. of coal, as fired, dry coal, or combustible (Lines 42 and 43 and footnote)	14,220	14,510	100.00	15,800	100.0

If the fuel lost in ash and refuse is not the combustible of the original coal, but coke or carbon of a heating value of 14,600 B.T.U. per lb., then the heat loss due to it is $0.05 \times 14{,}600 = 730$ instead of 790 B.T.U. The heating value per lb. of combustible burned would then be $(14{,}220-730) \div 0.85 = 15{,}870$ instead of 15,800. The percentage figures in the last column would be changed accordingly, and the efficiency of the boiler and furnace would be $(11{,}711 \div 15{,}870) = 73.78\%$ instead of 74.1%.

In this table the calculations expressed in the text (excepting Item *a*) refer to the quantities given in the first column, which are based on coal as fired. The quantities in the second column, which are based on dry coal, are obtained from those in the first column by dividing each one by

$$\frac{100-2}{100} = 0.98.$$

The items are designated the same as those given in the tabular form of the report under Item 55.

DETERMINING THE MOISTURE IN COAL.*

Until recently two methods of determining moisture in coal have been in common use: first, the one usually adopted in boiler-testing, which consists in drying a large sample, fifty pounds or more, in a shallow pan placed over the boiler or flue; second, the method usually followed by chemists, of drying a one-gram sample of pulverized coal at 212° F., or a little above, for an hour, or until constant weight is obtained. Both methods are liable to large errors. In the first method, the temperature at which the drying takes place is uncertain, and there is no means of knowing whether the temperature obtained is sufficient to drive off the moisture that is held by capillary force or other attraction within the lumps of coal, which, at least in case of bituminous coals seems to be as porous as wood, and as capable of absorbing moisture from the atmosphere. The second method is liable to greater errors in sampling than the first, and during the process of fine crushing and passing through sieves, a considerable portion of the moisture is apt to be removed by air-drying. In an extensive series of boiler-tests made by the writer in the summer of 1896, it became necessary to find more accurate means of determining moisture than either of those above described. It was found by repeated heating at gradually increasing temperatures from 212° up to 300° or over, and weighing at intervals of an hour or more, that the weight of coal continually decreased until it became nearly constant, and then a very slight increase took place, which increase became greater on further repeated heatings to temperatures above 250°. It has often been stated that if coal is heated above 212° F., volatile matter will be driven off; but repeated tests on seventeen different varieties of coal mined in western Pennsylvania, Ohio, Indiana, Illinois and Kentucky invariably showed a gradual decrease of weight to a minimum, followed by the increase, as stated above, and in no single case was there any perceptible odor or other indication of volatile matter passing off below a temperature of 350°. The fact that no volatile matter was given off was further proved by heating the coal in a glass retort and catching the vapor driven off in a bottle filled with water and inverted in a basin; the air displaced from the retort by expansion due to the heating displacing the water in the bottle. When the retort was cooled, after being heated to 350° in an oil bath, the air thus expanded contracted, and returned from the bottle to the retort, leaving the bottle full of water, as at the beginning of the heating, showing that no gas had been given off, except possibly such exceedingly small amount as might be absorbed by he water. The method described in Section XV of the report † was then adopted as the best available method of determining the moisture in these coals. Its accuracy was further checked by other methods.‡

The new method of drying and its results were communicated by the writer to Prof. R. C. Carpenter of Cornell University, shortly after they were made, and he thereupon began experimenting with the method, and fully confirmed the writer's conclusions. In a letter dated May 18, 1897, he says: "We have investigated the moisture question, and find that in all the samples tested, some four or five in number, there is no appreciable loss between temperatures 250 and 350 degrees; at least the loss is less than our means of weighing." In his paper on "Hygrometric Properties of Coals," presented at the Hartford, meeting (Transactions, vol. xviii. p. 948), he says:

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* This and following articles are from the signed appendices to the Code of 1899, somewhat abridged. The initials are those of Geo. H. Barrus, J. C. Hoadley, and the author.

† The same method is recommended in the Report of the Power Test Committee in 1915.

‡ For scientific investigations in which extreme accuracy is desired, the author would suggest that the coal be dried in an atmosphere of nitrogen, to avoid oxidation, and that the moisture driven off be absorbed by chloride of calcium and weighed. The loss of weight by the coal should equal the gain of weight by the chloride of calcium if no volatile matter is driven off.

"With the most volatile coals, there is no sensible loss of weight due to driving off the volatile matter under a temperature of 380° Fahr., and with an anthracite coal there is no sensible loss under a temperature of 700° Fahr."

W. K.

DETERMINATION OF THE MOISTURE IN THE STEAM.

The throttling steam calorimeter,* first described by Professor Peabody in Trans. A.S.M.E., vol. x. page 327, and its modifications by Mr. Barrus vol. xi. page 790; vol. xvii. page 617; and by Professor Carpenter, vol. xii. page 840; also the separating calorimeter designed by Professor Carpenter, vol. xvii. page 608; which instruments are used to determine the moisture existing in a small sample of steam taken from the steam-pipe, give results, when properly handled, which may be accepted as accurate within 0.5 per cent (this percentage being computed on the total quantity of the steam) for the sample taken. The possible error of 0.5 per cent is the aggregate of the probable error of careful observation, and of the errors due to inaccuracy of the pressure-gauges and thermometers, to radiation, and, in the case of the throttling-calorimeter, to the possible inaccuracy of the figure 0.46 for the specific heat of superheated steam, which is used in computing the results. It is, however, by no means certain that the sample represents the average quality of the steam in the pipe from which the sample is taken. The practical impossibility of obtaining an accurate sample, especially when the percentage of moisture exceeds two or three per cent, is shown in the two papers by Professor Jacobus in Transactions, vol. xvi. pages 448, 1017.

In trials of the ordinary forms of horizontal shell and of watertube boilers, in which there is a large disengaging surface, when the water-level is carried at least 10 inches below the level of the steam outlet, and when the water is not of a character to cause foaming, and when in the case of water-tube boilers the steam outlet is placed in the rear of the middle of the length of the water-drum, the maximum quantity of moisture in the steam rarely, if ever, exceeds two per cent; and in such cases a sample taken with the precautions specified in the Code may be considered to be an accurate average sample of the steam furnished by the boiler, and its percentage of moisture as determined by the throttling or separating calorimeter may be considered as accurate within one-half of one per cent. For scientific research, and in all cases in which there is reason to suspect that the moisture may exceed two per cent, a steam separator should be placed in the steam-pipe, as near to the steam outlet of the boiler as convenient, well covered with felting, all the steam made by the boiler passing through it, and all the moisture caught by it carefully weighed after being cooled. A convenient method of obtaining the weight of the drip from the separator is to discharge it through a trip into a barrel of cold water standing on a platform scale. A throttling or a separating calorimeter should be placed in the steam-pipe, just beyond the steam separator, for the purpose of determining, by the sampling method, the small percentage of moisture which may still be in the steam after passing through the separator.

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*The throttling calorimeter is based on the fact that steam containing a small percentage of moisture is dried by throttling and superheated to a temperature above that due to its reduced pressure. It consists essentially of ½-in. pipe fittings containing a flange coupling in which is inserted a thin blank flange or disk perforated with a hole ⅛ in. or less in diameter. The steam from the sampling pipe passes through this hole into a small exhaust chamber fitted with a mercury well and thermometer. The difference between the temperature of the throttled steam, as shown by this thermometer and that due to its pressure (subject to a slight correction for radiation) is the superheating, and from this the moisture is calculated by a formula which is based on the principle that the total heat of the moist steam before throttling is the same as that of the dry steam after throttling if there is no loss or gain of heat by radiation or conduction. To lessen the transfer of heat by conduction, asbestos washers should be placed on each side of the disk, and to lessen radiation the whole instrument should be enclosed in a non-conducting covering.

The formula for calculating the percentage of moisture when the throttling calorimeter is used is the following:

$$w = 100 \times \frac{H - h - k(T - t)}{L},$$

in which w = percentage of moisture in the steam, H = total heat, and L = latent heat per pound of steam at the pressure in the steampipe, h = total heat per pound of steam at the pressure in the discharge side of the calorimeter, k = specific heat of superheated steam, T = temperature of the throttle and superheated steam in the calorimeter, and t = temperature due to the pressure in the discharge side of the calorimeter, = 212° Fahr., at atmospheric pressure. Taking $k = 0.46$ and $t = 212$, the formula reduces to

$$w = 100 \times \frac{H - 1150.4 - 0.46(T - 212)}{L}.$$

W. K.

CORRECTION FOR RADIATION FROM THROTTLING CALORIMETERS.

The formulæ usually given for determining moisture in a throttling calorimeter makes no allowance for radiation from the exterior surfaces of the instrument. It is true that this allowance is small and does not affect the results but a small fraction of 1 per cent; but it nevertheless exists, and should properly be taken into account. In my own work I have found that the radiation reduces the temperature of the wire-drawn steam some six degrees, and this represents about 0.3 of 1 per cent of moisture. My practice is to allow for the radiation by determining the normal temperature for the instrument by obtaining a reading of the thermometer when the fires are in a dead condition and the superheat has disappeared; this temperature being observed when the pressure as shown by the gauge is the average of the readings taken during the trial. Observations being made by the same instrument, errors of gauge or thermometer are practically eliminated.

G. H. B.

"NORMAL READING" OF A CALORIMETER.*

To determine the "normal" reading of the low-pressure thermometer corresponding to dry steam, the instrument should be attached to a horizontal steam pipe in such a way that the sampling nozzle projects upwards to near the top of the pipe, there being no perforations and the steam entering through the open top of the nozzle. The test should be made when the steam in the pipe is in a quiescent state, and when the steam pressure is maintained constantly at the point observed on the main trial. If the steam pressure falls during the time when the observations are being made, the test should be continued long enough to obtain the effect of an equivalent rise of pressure.

To find the "constant" for 1 per cent of moisture, divide the latent heat of the steam supplied to the calorimeter at the observed pressure or temperature by the specific heat of superheated steam at atmospheric pressure (0.46) and divide the quotient by 100.

Finally ascertain the percentage of moisture by dividing the number of degrees of cooling by the constant, as above noted.

To determine the quantity of steam used by the calorimeter it is usually sufficient to calculate the quantity from the area of the orifice and the absolute pressure, using Napier's formula for the number of pounds passing through per second; that is, absolute pressure in lb. per sq. in divided by 70 and multiplied by the area of orifice in sq. in. To determine the quantity

* From Appendix to Code of 1915.

by actual test, a steam hose may be attached to the outlet of the calorimeter and carried to a barrel of water on platform scales. The amount of steam condensed in a certain time is determined and thereby the quantity discharged per hour.

COMBINED CALORIMETER AND SEPARATOR.

A form of steam calorimeter which the writer uses is termed the "1895 pattern" universal steam calorimeter, and is a modification of the one described in the Transactions, vol. xi. p. 790. It is illustrated in the accompanying cut, Fig. 248, which is reprinted from p. 618, vol. xvii. in the Transactions. It consists of a throttling calorimeter and separator combined, the latter being attached to the outlet where the steam of atmospheric pressure is escaping. If the moisture is too great to be determined by the readings of the two thermometers, the separator catches the balance, and the total quantity of moisture is made up in part of that shown by the thermometers, and in part of that collected from the separator.

G. H. B.

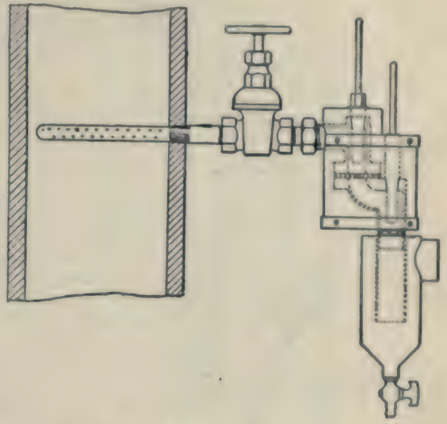

FIG. 248.—STEAM CALORIMETER.

EFFICIENCY OF THE BOILER.

The efficiency of the boiler, not including the grate (or the efficiency based upon con bustible) is a more accurate measure of comparison of different boilers than the efficiency including the grate (or the efficiency based upon coal); for the latter is subject to a number of variable conditions, such as size and character of the coal, air-spaces between the grate-bars, skill of the fireman in saving coal from falling through the grate, etc. It is, moreover, subject to errors of sampling the coal for drying and for analysis, which affect the result to a greater degree than they do the efficiency based upon combustible, for the reason that the heating value per pound of combustible of any sample selected from a given lot, such as a car-load, of coal is practically a constant quantity and is independent of the percentage of moisture and ash in the sample; while the sample itself, upon the heating value of which the efficiency based on coal is calculated, may differ in its percentage of moisture and ash from the average coal used in the boiler-test.

When the object of a boiler-test is to determine its efficiency as an absorber of heat, or to compare it with other boilers, the efficiency based on combustible is the one which should be used; but when the object of the test is to determine the efficiency of the combination of the boiler, the furnace, and the grate, the efficiency based on coal must necessarily be used.

W. K.

DRAFT-GAUGE.

The ordinary form of draft-gauge, consisting of the U tube (Fig. 249), containing water, lacks sensitiveness when used for measuring small quantities of draft. An instrument which the writer has used satisfactorily for a number of years multiplies the ordinary indications as many times as desired.

It consists of a U tube made of $\frac{1}{2}$-in. glass, surmounted by two larger tubes, or chambers, having a diameter of $2\frac{1}{2}$ ins., as shown in Fig. 250. Two different liquids which will not mix, and which are of different color, are used, one occupying the portion AB, and the other the portion BCD. The movement of the line of demarcation is proportional to the difference in the areas of the chambers and of the U tube below. The liquids generally employed are alcohol colored red and a certain grade of lubricating oil. A multiplication varying from eight

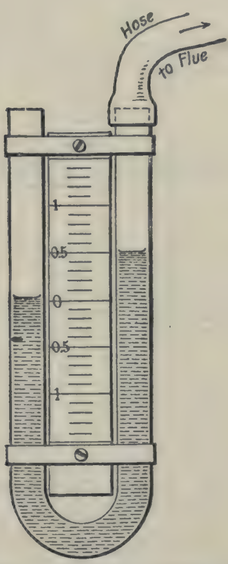

FIG. 249.—U-TUBE DRAFT-GAUGE, HALF SIZE.

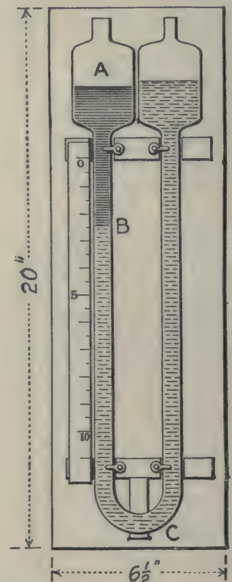

FIG. 250.—BARRUS'S DRAFT-GAUGE, WITH MAGNIFIED READINGS.

to ten times is obtained under these circumstances; in other words, with $\frac{1}{4}$-in. draft the movement of the line of demarcation is some 2 ins.

The instrument is calibrated by referring it to the ordinary U-tube gauge.

G. H. B.

DRAFT-GAUGE.

The accompanying sketch (Fig. 251) represents a very sensitive and accurate draft-gauge recently constructed by the writer. A light cylindrical tin can A, 5 ins. diameter and 6 ins. high, is inverted and suspended inside of a can B, 6 ins. diameter, 6 ins. high, by means of a long helical spring. Inside of the larger can a $\frac{1}{4}$-in. tube is placed, with one end just below the level of the upper edge, while the other end passes through a hole cut in the side of the can, close to the bottom, solder being run around the tube so as to close the hole and make the can water-tight. The can is filled with water to within about half an inch of the top, and the inner can is suspended by the spring so that its lower edge dips into the water, the height of the support of the spring being adjusted accordingly.

The small tube being open at both ends, the air enclosed in the can A is at atmospheric pressure, and the spring is extended by the weight of the can

The end of the tube which projects from the bottom of the can being now connected by means of a rubber tube with a tube leading into the flue, or other chamber whose draft or suction is to be measured, air is drawn out of the can A until the pressure of the remaining air is the same as that of the flue. The external atmosphere pressing on the top of the can A causes it to sink deeper in the water, extending the spring until its increased tension just balances the difference of the opposing vertical pressures of the air inside and outside of the can. The product of this difference in pressure, expressed as a decimal fraction of a pound per square inch, multiplied by the internal area of the can in square inches, equals the tension of the spring (above that due to the weight of the can) in pounds or fraction of a pound. The extension of a helical spring being proportional to the force applied, the distance travelled downward by the can A measures the force of suction, that is, the draft. The movement of the can may conveniently be measured by having a celluloid scale graduated to 50ths of an inch fastened to the side of the can A, and a fine pointer fixed to the upper edge of the can B, almost touching the scale.

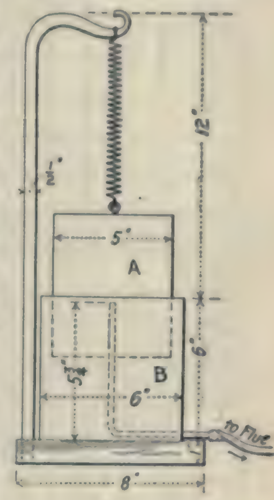

FIG. 251.—DRAFT-GAUGE FOR LIGHT PRESSURES.

To reduce the readings of the scale to their equivalents in inches of water-column, as read on the ordinary U-tube gauge, we have the following formulæ:

Let P = force in pounds required to stretch the spring 1 in.;
E = elongation of the spring in inches;
A = area of the inner can in square inches;
d = difference in pressure or force of the draft in pounds per square inch;
D = difference in pressure in inches of water = $27.71d$.

$$EP = Ad = \frac{AD}{27.71} = 0.0361AD,$$

$$D = \frac{27.71EP}{A},$$

$$E = \frac{0.0361AD}{P}.$$

The last equation shows that for a constant force of draft the elongation of the spring or the movement of the can may be increased by increasing the area of the can or by decreasing the strength of the spring. The strength of the spring may be increased, that is, its sensitiveness may be decreased, by increasing either its length or the diameter of the helix, or by decreasing the diameter of the wire of which it is made. We thus have at command the means of making the apparatus of any desired degree of sensitiveness.

Applying the above formulæ, let it be required to determine the movement of the can corresponding to a draft of 1 in. of water-column, the can A having a diameter of 5 ins. = 19.63 ins. area, and the spring of such a strength that 0.1 lb. elongates it 1 in. Here $P = 0.1$; $A = 19.63$; $D = 1$.

$$E = \frac{0.0361 \times 19.63}{0.1} = 7.09 \text{ inches}.$$

That is, the instrument multiplies the readings of the U tube 7.09 times. The precision of the instrument is, however, far greater than this figure would indicate; for in the U tube it is exceedingly difficult to read with precision the difference in height of the two menisci, while with this apparatus readings in the scale may easily be made to $\frac{1}{50}$ in., which, with the multiplication of 7, is equivalent to $\frac{1}{350}$ of an inch of water-column. The instrument may also be calibrated by directly comparing its readings with those of an ordinary U-tube gauge.

W. K.

SAMPLING FLUE-GASES.

Very great diversities in the composition of flue-gases often exist in the same flue at the same time. To obtain a fair sample, it has been found sufficient to have one orifice to draw off gases through for each 25 sq. ins. of cross-section of flue. The pipes must be of equal diameter and of equal length. One-quarter-in. gas-pipes, all alike at the ends, and of equal lengths, answer well. Similar steel tubes will be still better (because smoother and more uniform). These should be secured in a box or block of galvanized sheet iron, equal in thickness to one course of brick, in such a manner that the open ends may be evenly distributed over the area of the flue *A* (Fig. 252), and their other open enclosed in the receiver *B*. If the flue-gases be drawn off from the receiver *B* by four tubes, *CC*, into a mixing-box *D* beneath, about 3-in. cube, a good mixture can be obtained. Two such "samplers," one above the other a foot apart, in the same flue, will furnish samples of gases which show by analysis the same composition.

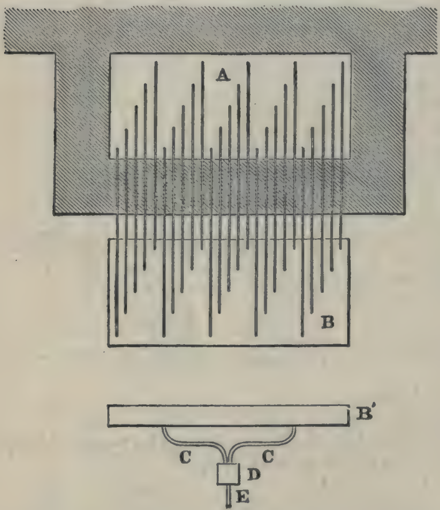

FIG. 252.—METHOD OF SAMPLING FLUE-GASES.

J. C. H.

THE RINGELMANN SMOKE-CHART.

Professor Ringelmann, of Paris, has invented a system of determining the relative density or blackness of smoke. In making observations of the smoke proceeding from a chimney, four cards ruled like those in the cut (Fig. 253), together with a card printed in solid black and another left entirely white, are placed in a horizontal row and hung at a point about 50 ft. from the observer and as nearly as convenient in line with the chimney. At this distance the lines become invisible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards, which are numbered from 0 to 5, determines which card most nearly corresponds with the color of the smoke and makes a record accordingly, noting the time. Observations should be made continuously during say one minute, and the estimated average density during that minute recorded, and so on, records being made once every minute. The average of all the records made during a boiler-test is taken as the average figure for the smoke density during the test, and the whole of the record is plotted on cross-section paper in order to show how the smoke varied in density

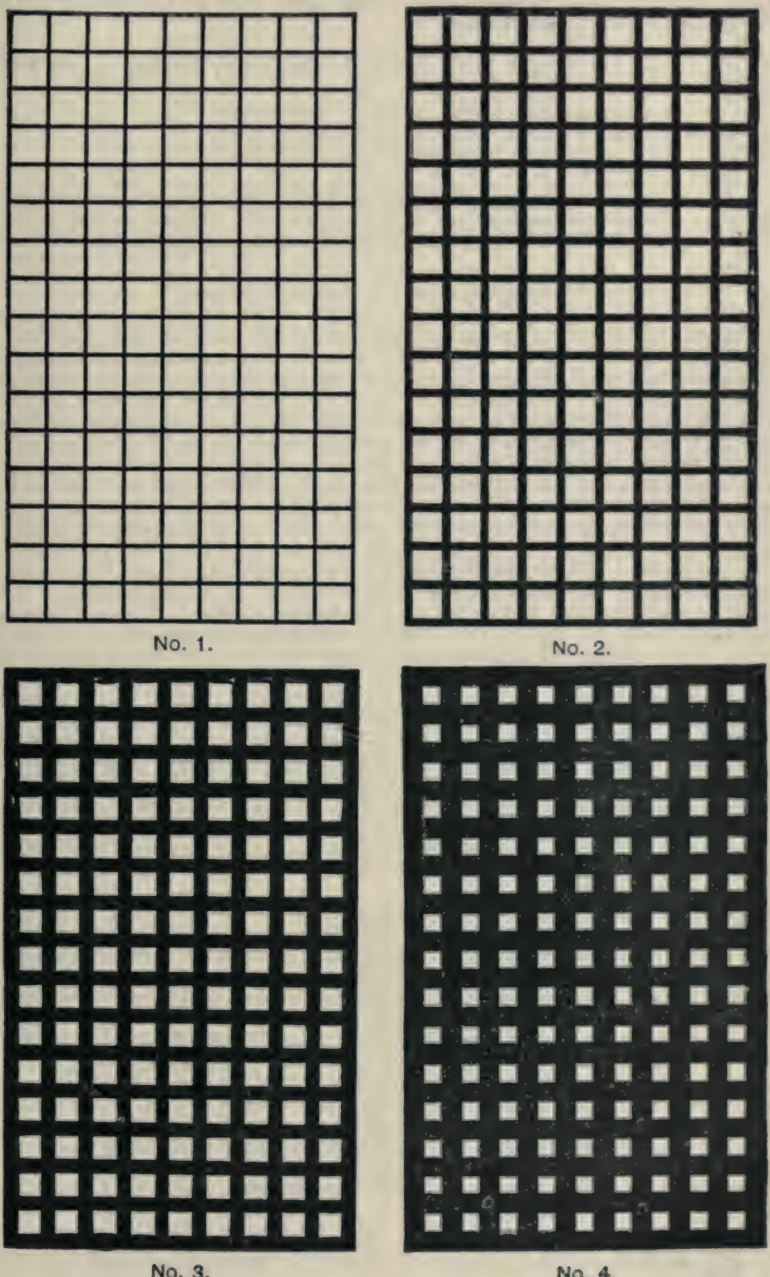

FIG. 253.—THE RINGELMANN SCALE FOR GRADING THE DENSITY OF SMOKE.

from time to time. A rule by which the cards may be reproduced is given by Professor Ringlemann as follows:

Card 0—All white.

Card 1—Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.

Card 2—Lines 2.3 mm. thick, spaces 7.7 mm square.

Card 3—Lines 3.7 mm. thick, spaces 6.3 mm. square.

Card 4—Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 5—All black.

The cards as printed on the opposite page are much smaller than those used by Professor Ringelmann. The thickness and spacing of the lines are in the same proportion, but reduced to one-half size.

W. K.

STARTING AND STOPPING A TEST.

A special caution is needed against a modification of the "alternate" method,* which has been adopted by some testing engineers within the past few years. It consists in taking the starting and the stopping times each at a time subsequent to the cleaning, say after 400 lbs. of coal has been fired since the cleaning. There are two sources of serious error in this method, one causing an incorrect measurement of the coal, the other an incorrect measurement of the water. Suppose 200 lbs. of hot coke are left on the grate at the end of cleaning and 400 lbs. of fresh coal are added by the end of, say, half an hour after cleaning. If the coal left at the end of the cleaning, and the boiler-walls also, are very hot, and the coal is highly volatile and dry and the pieces of such size as not to choke the air-supply, the fire may burn so briskly that at the end of the half-hour the fuel-value of the partly-burned coal left out of the total 600 lbs. is equivalent only to 200 lbs. of coal. If, on the contrary, the hot coke on the grates at the end of the cleaning, and the boiler-walls, are considerably cooled, if the fresh coal fired is moist and of small size, such as the slack of run-of-mine bituminous coal, which is often found in one portion of a pile in greater quantity than in another, the fire during the half-hour may burn so sluggishly that the coal and coke on the grate at the end of the half-hour may have a fuel-value equal to 400 lbs. of coal. If, in this case, it is assumed that the quantity and condition of the coal at the end of the half-hour after cleaning are the same at the starting and stopping time; and, if the fire burned briskly during the half-hour before starting and slowly during the half-hour before stopping, the boiler will be charged with more coal than was actually burned. If, on the contrary, the coal burns away more slowly during the half-hour after the cleaning before the starting time and more rapidly during the half-hour before the end of the test, the boiler is not charged with as much coal as was actually burned.

The error in water-measurement is due to the fact that the condition of the fire, and especially the quantity of flaming gases arising from it, influences the height of the water-level. A bright hot fire, or a fire with an abundance of burning gas proceeding from it, causes the water-level to rise; while anything that cools the furnace, such as freshly-fired coal, an open fire-door, or a check to the draft, causes the water-level to fall. A rise or a fall of several inches in a few seconds frequently occurs when bituminous coal is used. If the water-level is noted at the starting of the test, when it is raised by a bright fire, and at the end of a test, when it is depressed by the stoppage of violent ebullition or of rapid circulation, due to the cooling of the fire, the boiler will be credited with more water than was really evaporated, and *vice versa*.

The only correct times to be noted as the starting and the stopping times are when the smallest amount of fuel is on the grate and when it is in the most burned-out condition; that is, just before firing fresh coal after cleaning, and

* The "alternate" method of the Code of 1899 is the standard method of the Code of 1915. The old standard method, which consisted in starting with a wood fire and stopping by burning down and withdrawing all ash and unburned coal from the grate, is now abandoned.

when the water-level is in its most quiet condition and the least raised by ebullition. The furnace-door has then been kept open for some time for cleaning and the furnace therefore is in its coolest state. This condition of fire and of water-level can be duplicated immediately after cleaning the fire; but there is no certainty of duplication of any condition when there is a bright fire and consequent rapid steaming.

These statements are not based upon theoretical considerations, but are the results of many experiments made by the writer to determine the best starting and stopping times. In a long series of tests with bituminous coals no less than six different times were recorded as starting times and as many as stopping times, and the coal apparently used and the water apparently evaporated recorded and calculated for each. These times were: *A*, before opening the first or right-hand door to clean the fire; *B*, after cleaning the first half of the furnace and just before firing fresh coal; *C*, after cleaning the second half of the furnace; *D*, after 200 lbs. of fresh coal had been fired; *E*, after 400 lbs.; *F*, after 600 lbs. By plotting the apparent water-evaporation between *A* and *E*, both for starting and for stopping times, it was seen that there was nearly always an apparent negative evaporation between *B* and *D*, and sometimes between *B* and *C* and between *B* and *E*, due to the correction for height of observed water-level, the level rising rapidly, being much greater than the water fed by the pump. There was often no similarity of appearance of the plotted diagrams between *A* and *F* at the beginning and at the end of the same test. The possible error of water-measurement due to taking *A*, *D*, *E*, or *F* as the starting time was sometimes as much as 2000 lbs. of water, or about 3 per cent of the whole amount evaporated in a ten-hour test. The record of water evaporated between the stopping and starting times *C* occasionally differed considerably from that taken between the *B* start and stop, due to the fact that sometimes between *B* and *C* there was a sudden lighting up of the fresh coal on the cleaned side of the furnace, while at other times the fire would not light up brightly until after the *C* point had passed. It was therefore decided that the *B* time, when the furnace was the coldest and the water-level at the lowest, was the only time which could be accepted as the true starting and stopping time.

W. K.

CHART SHOWING GRAPHICALLY THE LOG OF A TRIAL.

The well-known method of plotting observations and data on cross-section paper, and making a chart applying to the test, is a useful means of representing the exact uniformity of conditions existing during a trial. Such a chart is illustrated in the appended cut (Fig. 257), in which the abscissæ represent times and the ordinates on appropriate scales the various observations and data.

G. H. B.

Computation of the Results of a Boiler Trial.—The following example shows a convenient method of making the calculations of the results of a trial from the observed data recorded at the trial.

The observed data used in the calculations are:

a. Duration of the test.....................10 hrs. 15 min. = 10.25 hrs.
b. Water apparently evaporated.....................lbs. 30,000
c. Coal used.....................................lbs. 3,000
d. Feed-water temperature, average.....................110° F.
e. Steam-pressure by gauge, average.....................lbs. 120
f. Moisture in the coal.....................................% 2
g. Moisture in the steam.....................................% 0.5
h. Ash and refuse withdrawn from the fire..........6% = lbs. 180
i. Grate-surface.....................................sq. ft. 30
j. Heating surface.....................................sq. ft. 1,000

The following results are calculated from these data:

k. Factor of evaporation, from d and e, taken from table of factors, 1.15.

b_1 Water evaporated, corrected for moisture in the steam $= b - gb = 30{,}000 - 150 = 29{,}850$ lbs.

U.E. Water evaporated from and at 212° into dry steam $= b_1 \times k = 29{,}850 \times 1.15 = 34{,}327$ lbs.

c_1 Dry coal $= c - f = 3000 - 60 = 2940$ lbs

c_2 Combustible $= c_1 - h = 2940 - 180 = 2760$ lbs.

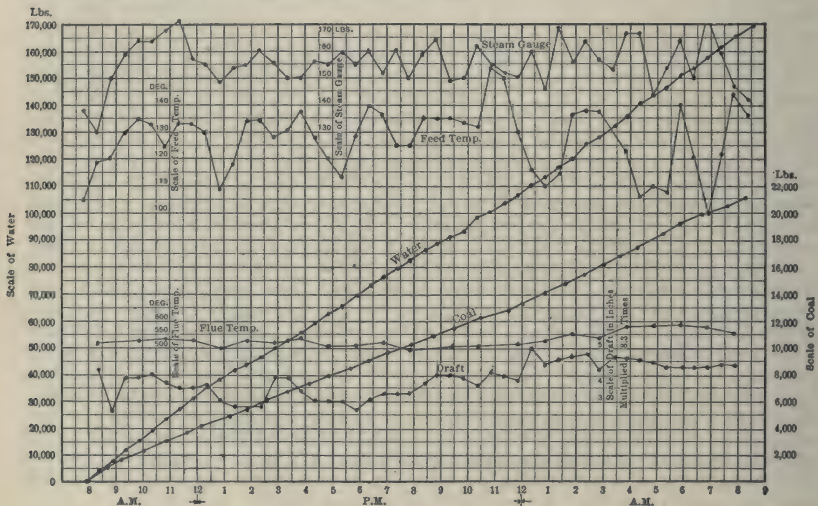

FIG. 254.—GRAPHIC RECORD OF A BOILER TEST.

USEFUL RESULTS.

(1) $b \div c$ Water apparently evaporated per lb. coal, actual conditions $30{,}000 \div 3000 = 10$ lbs.

(2) U.E. $\div c$ Water evaporated from and at 212° per lb. coal, $34{,}327 \div 3000 = 11.442$ lbs.

(3) U.E. $\div c_1$ Water evaporated from and at 212° per lb. dry coal, $34327 \div 2940 = 11.676$ lbs.

(4) U.E. $\div c_2$ Water evaporated from and at 212° per lb. combustible, $34{,}327 \div 2760 = 12.437$ lbs.

(5) H.P. Horse-power = U.E. $\div a \div 34.5 = 34{,}327 \div 10.25 \div 34.5 = 97.1$ H.P.

(6) Coal per sq. ft. grate-surface per hour, $c \div a \div i = 3000 \div 10.25 \div 30 = 9.76$ lbs.

(7) U.E per sq. ft. heating surface per hour, U.E. $\div a \div j = 34{,}327 \div 10.25 \div 1000 = 3.35$ lbs.

(8) T. Temperature of the chimney gases, average 450° F.

Interpretation of the above results.—The results given in the last eight lines are the ones that give practically all the information that is required from any boiler-trial.* All the observed data and all the computations are of use only for the purpose of obtaining these eight results. We will now consider what conclusions may be drawn by an engineer from these eight results alone, the figures themselves being accepted as correct.

* That is, an ordinary trial in a small plant. In large plants the results here given should be supplemented by coal and gas analyses, and by a heat-balance computed from them.

1. From the result, 10 lbs. of water evaporated under actual conditions nothing can be known concerning the efficiency of the boiler or the quality of the coal, unless the conditions of feed-water temperature, steam-pressure, and moisture in the coal and in the steam are also known. About the only use that can be made of this figure is in connection with estimates of the cost of steam-power. If the engine using the steam furnished by the boiler uses 20 lbs. of steam per horse-power per hour, then it will require $20 \div 10 = 2$ lbs. of coal per horse-power, the "actual conditions" under which the boiler is operated being the pressure of steam required by the engine and the temperature of water in the hot-well of the condenser or in the feed-water heater, both of which obtain their heat from the exhaust steam furnished by the engine.

2. The result, 11.442 lbs. evaporated from and at 212° per lb. of coal, is useful as a measure of the quality of the coal, provided the efficiency of the boiler is known. For tests of different coals with the same boiler and under the same conditions of rate of driving, kind of firing, etc., this figure is the one that will be used in comparing the relative values of the coals. It is a very high figure, and indicates both that the coal is of good quality and that the efficiency of the boiler is high.

3. The result, 11.676 U.E. per lb. of dry coal, is useful in connection with result 2, as a measure of the quality of the coal. The difference between the two results being 2% shows that that is the percentage of moisture in the coal, and this would indicate that the coal is not Western coal. The result would also be used in comparing tests of coals of one grade, but differing in surface-moisture, so as to reduce them all to the standard of dry coal. It is practically of no use in comparing coals of different grades, such as Pittsburg and Illinois coals, containing, respectively, say 2% and 12% of moisture.

4. The result, 12.437 U.E. per lb. of combustible, is the one used for comparing boiler efficiencies. If the grade of coal is known, and its heating value per lb. of combustible is either known as the result of a calorimetric test or by computation from analysis, or estimated from the average heating value per lb. combustible of coal of that grade, then the figure 12.437 divided by the quotient of the heating value of the coal divided by 965.7 will give the efficiency. The figure 12.437 being in excess of 12 lbs., which is practically the maximum value obtainable for anthracite, and beyond the maximum for bituminous coal, indicates both that the coal is semi-bituminous and that the boiler was operated with a very high efficiency. Taking the average heating value of semi-bituminous coal at 15,750 B.T.U. per lb. combustible, gives

$$\frac{12.437}{15{,}750 \div 965.7} = 76.26\% \text{ efficiency.}$$

5. The result, 97.1 H.P., is the measure of the capacity of the boiler developed in the trial. This figure will be compared with the boiler's rated or nominal capacity.

6. The result, 9.76 lbs. of coal per sq. ft. of grate per hour, is the measure of rate of driving of the grate-surface. It is a rather low figure for semi-bituminous coal in average practice. Taken in connection with the high efficiency it indicates exceptionally good firing, very nice adjustment of the thickness of bed of coal on the grate to the force of the draft, and an excellent furnace, a combination of favorable conditions not often obtained.

7. The rate of driving, 3.35 U.E. per sq. ft. of heating surface per hour, is a little higher than that at which maximum economy is to be expected, but, with the exceptionally favorable conditions mentioned in the preceding paragraph, it may be the rate corresponding to maximum economy in this case.

8. The temperature of the chimney-gases, 450° F., is unusually low for semi-bituminous coal in ordinary practice. It indicates, when taken in connection with the high efficiency, which is inconsistent with air-leaks in the setting, a high furnace temperature and a clean boiler, both of which tend to produce a low chimney temperature.

Erroneous Conclusions from Competitive Tests.—A certain water-tube boiler was reported to have shown 9.6% saving of fuel as compared with a return-tubular boiler in a competitive test. Both were fired with semi-bituminous coal under regular working conditions. Examining the data we find that there were five tests of the water-tube boiler, the rates of driving ranging from $W/S = 2.49$ to 2.92, averaging 2.64 lbs. evaporated from and at 212° per sq. ft. of heating surface per hour, and the efficiencies from 71.5 to 77.0%, averaging 73.8%; while there was only one test of the fire-tube boiler, with $W/s = 3.10, E = 67.3\%$. The saving in this case is not $(73.8 - 67.3) \div 67.3 = 9.6\%$, but only $(73.8 - 67.3) \div 73.8 = 8.8\%$. In computing the saving from the figures of efficiency, the divisor should always be the higher figure. The only conclusion that should be drawn from these tests is that the fire-tube boiler gave a result considerably lower than it should have given with proper firing, a clean boiler, no air leaks in the setting, and a sufficiently large back connection to insure that the hot gases flowed uniformly through all the tubes.

Another set of tests with the same type of water-tube boiler gave us an average of five tests $W/S = 3.11$, $E = 72\%$, as compared with the result from another type of water-tube boiler, $W/S = 3.37$, $E = 64.5\%$. The coal was the same, a high grade of semi-bituminous. No information is given about the furnace with which the other type was equipped; it may have been an anthracite furnace. The falling off of 7.5% efficiency should not have been considered the fault of the other water-tube boiler itself, but of some conditions of the furnace or of firing, air leaks, damaged baffling walls, or other cause.

Great care should be used in drawing conclusions from the results of comparative boiler tests made with and without the use of some special appliance. If a test made to prove that a certain device improves the efficiency of a boiler gives a figure of 70 per cent when it is used and only 60 per cent when it is not, it by no means follows that the use of the device was the cause of the apparent improvement. Some slight change in the method of firing, in the thickness of the coal bed, or in the force of the draft, may have caused all the difference, and more than 70 per cent might have been obtained without the device, under proper conditions of firing and draft.

Vertical versus Horizontal Baffling of Water-tube Boilers.—Kreisinger and Ray (*Power,* August 19, 1913), describe a series of tests with two kinds of coal to determine whether horizontal or vertical baffles in a Babcock & Wilcox type of boiler gave the highest efficiency. The principal average results were as follows:

The coals were Pocahontas, W. Va., and Clinchfield, Va., the former containing 18 and the latter 35 per cent volatile matter in the combustible. The authors conclude that the horizontal baffling gives much better results than the vertical, and that in the horizontal

Kind of Baffling	Vertical.		Horizontal, 2 passes.		Horizontal, 3 passes.	
Kind of Coal	Semi-bit.	Bit.	Semi-bit.	Bit.	Semi-bit.	Bit.
Number of tests	4	3	4	3	3	2
H.P. developed, per cent of rating	128	114	113	137	119	122
Excess air, per cent	128	158	99	109	....	102
Efficiency, boiler and grate.	61.3	60.9	63.6	67.2	67.7	69.9

3-pass boiler the draft over the fire is considerably reduced, hence there is less chance of drawing too much air into the furnace. No general conclusion as to the relative merits of horizontal and vertical baffling can be drawn from these tests. With the vertical baffling there was far too great an excess of air, which might have been avoided either by carrying heavier fires or by checking the draft by the chimney damper, and the combustion chamber was far too small, the furnace being adapted only for anthracite coal. With the horizontal baffling the excess air supply was less, and the combustion chamber much larger.

CHAPTER XVII.

RESULTS OF STEAM-BOILER TRIALS.

In this chapter the results of trials of several different boilers will be given, together with comments which may be useful to students of the subject. Mere tables of results of individual boiler-tests are of little use until they are collated and compared with a view to discover the various causes or conditions which contributed to the results obtained.

Range of Economy found in Actual Practice.—In Donkin's "Heat Efficiency of Steam-boilers" there are fifty tables containing the results of 425 experiments on boilers of different types. The following table is a brief summary of the highest, lowest, and mean efficiencies obtained in 405 experiments with different boilers without economizers:

EFFICIENCY PER CENT.

Type of Boiler.	Number of Experiments.	Mean of Two best Results.	Lowest, One Experiment.	Mean of All Experiments.	Type of Boiler.	Number of Experiments.	Mean of Two best Results.	Lowest, One Experiment.	Mean of All Experiments.
Water-tube*	6	84.1	66.6	77.4	Elephant	7	70.8	58.9	65.3
Locomotive	37	83.3	53.7	72.5	Water-tube†	49	77.5	50.0	64.9
Lancashire	10	74.4	65.6	72.0	Lancashire	40	73.0	51.9	64.2
Two-story	9	76.1	57.6	70.3	Cornish	3	65.9	60.0	62.7
Two-story	29	79.8	55.9	69.2	Lancashire	107	79.5	42.1	62.4
Dry-back	24	75.7	64.7	69.2	Dry-back	6	73.4	54.8	61.0
Return tube	11	81.2	56.6	68.7	Lancashire‡	6	66.7	52.0	59.4
Cornish	25	81.7	53.0	68.0	Elephant	8	65.5	54.9	58.5
Cornish	9	81.0	55.0	67.0	Lancashire	8	74.3	45.9	57.3
Wet-back	6	69.6	62.0	66.0	Vertical	5	76.5	44.2	56.2

* 1½-in. tubes. † 4-in. tubes. ‡ Three-flue.

About the only conclusions that may be drawn from this table are that with many different varieties of boilers there may be obtained efficiencies which are so high as to be scarcely credible; that with the same types of boilers in other trials the results are so low that they can only be accounted for by improper firing or some other unfavorable condition; and that economy does not depend on the type of boiler. In 107 tests of Lancashire two-flue boilers the efficiencies varied from

79.5 down to 42.1 per cent, or all the way from nearly the highest possible figure down to the lowest one obtained in the whole series of tests.

In Mr. Geo. H. Barrus's book on Boiler Tests there are records of a great number of tests with different kinds of boilers, with different coals, and in different parts of the country. Selecting those tests of which complete records are given, we find the economy ranges as follows:

Water Evaporated from and at 212° per lb. Combustible.	Number of Tests Anthracite.	Number of Tests Semi-bit.	Number of Tests Bituminous.
Over 12 lbs.	..	6	..
11.5 to 12 lbs.	2	6	..
11 to 11.5 lbs.	10	5	..
10.5 to 11 lbs.	20	3	..
10 to 10.5 lbs.	11	5	1
9 to 10 lbs.	14	6	2
8 to 9 lbs.	8	3	..
6 to 7 lbs.	1	..	..
	66	34	3

Out of 66 tests with anthracite, only two gave a result over 11.5 lbs., a figure which may be reached with any type of boiler, properly designed and set, by a good fireman using good coal. Twenty-three out of the 66 boilers gave a result below 10 lbs., or 20 per cent less than the highest figure attainable. In the semi-bituminous tests only six boilers out of 34 gave 12 lbs., a figure which may easily be obtained with any good form of boiler, properly proportioned, properly set, and properly fired.

Mr. Barrus's Later Tests.—The tests referred to above were made between 1878 and 1888. In 1911 Mr. Barrus presented a paper at the Congress of Technology, in Boston, in which he gave the results of more than 300 tests that he had made since 1888. Arranging these tests in a similar table to the one given above we have the following:

Water Evaporated from and at 212° per Lb. Combustible. Lbs.	No. of Tests, Anthracite.	No. of Tests, Mixed Anth. and Soft.	No. of Tests, Semi-bit.	No. of Tests, Bituminous.
over 12	2	2	45	3
11.5 to 12	2	..	37	2
11 to 11.5	7	7	45	7
10.5 to 11	17	7	44	7
10 to 10.5	9	3	24	3
9 to 10	6	3	7	17
8 to 9	2	2	2	5
7 to 8	..	1	...	3
Total	45	25	204	47

This table shows no improvement in anthracite practice over the earlier tests, probably on account of the increasing use of the finer sizes, high in ash and moisture, but there is a notable improvement in the semi-bituminous tests, 84 per cent of them showing an evaporation of over 10.5 lbs. as compared with 59 per cent in the first table. This improvement is no doubt due to the use of improved furnaces and mechanical stokers. A study of the results of these later tests leads to the following conclusions:

1. Economy does not depend on the type of boiler.
2. With anthracite coal no special furnace is needed.
3. With semi-bituminous coal high economy is obtained with an ordinary furnace in only a few cases, in which the firing is exceptionally good, and generally high results are obtained only with special fire-brick furnaces or mechanical stokers.
4. High economy combined with high rate of driving can be obtained, only when all conditions are most favorable, including the regulation of air supply according to the analysis of the chimney gases.
5. The ordinary practice with volatile bituminous coals is much poorer than it should be, but high results are obtainable with mechanical stokers.

Tests of Stirling Boilers with Anthracite Coal.*—In 1894 Mr. Geo.. H. Barrus made a series of nine tests on two Stirling water-tube boilers at two colleries near Wilkes-Barre, Pa. From the reports of these tests the diagram and table on pages 599 and 601 have been prepared. Tests Nos. 1 and 2 inclusive were made on a 125-H.P. boiler at No. 5 shaft of the Lehigh and Wilkes-Barre Coal Co., and Nos. 8 and 9 were made on a 150-H.P. boiler at the Dorrance colliery of the Lehigh Valley Coal Co. The rating of the boilers is on the basis of 11½ sq. ft. of heating surface to a horse-power. Forced draft was supplied by McClave steam-blowers. The coal used in the several tests differed in size and quality. The sizes were determined by passing samples through and over screens of different meshes and weighing the portions thus separated. The coal used in five of the tests was as shown in the table on p. 599, the figures being given in percentages.

A Study of the Results of the Stirling Tests.—For comparing the results of these tests they have been plotted on the accompanying diagram, Fig. 255, showing the relation of the water evaporated per

* From *Mines and Minerals*, December, 1897.

Sizes of Screen.	Over $\frac{3}{16}$.	Through $\frac{3}{16}$	Through $\frac{1}{4}$.	Through $\frac{1}{16}$.	Through $\frac{1}{8}$.
Test No. 3. No. 2 buckwheat..	25	45	19	11	
" " 6. Culm, No. 5 shaft.	......	3	11	86	
" " 7. Culm, No. 4 shaft.	18	24.1	......	57.9	
" " 8. No. 2 buckwheat..	......	2.5	65	......	32.5
" " 9. No. 2 buckwheat..	......	10.7	67	......	22.3

pound of combustible, or the economy, to the rate of driving, or the water evaporated per square foot of heating surface per hour. For further comparison there are also plotted two dotted lines represent-

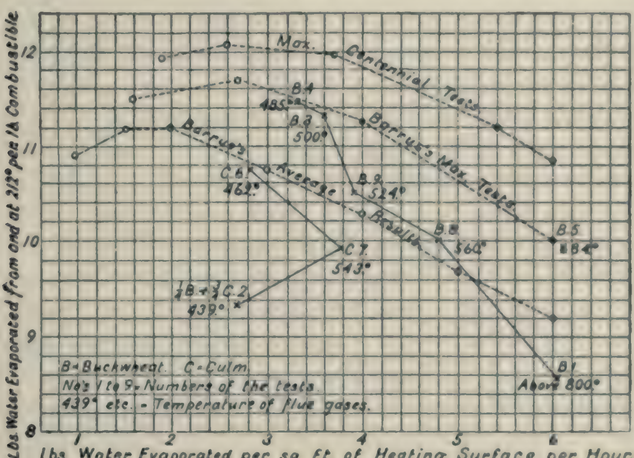

FIG. 255.—TESTS OF STIRLING BOILERS WITH ANTHRACITE BUCKWHEAT AND CULM COMPARED WITH TESTS RECORDED IN BARRUS ON "BOILER TESTS" AND WITH THE CENTENNIAL TESTS.

ing the maximum and the average results of tests with anthracite coal given in Mr. Barrus's book on "Boiler Tests," together with a line representing the maximum results obtained in the boiler-tests at the Centennial Exhibition. As the Centennial tests were made with egg coal of excellent quality and under the most favorable conditions, it is to be expected that their maximum results will be considerably above those obtained with buckwheat coal. Of the tests with buckwheat coal given in the above table, Nos. 3, 4, and 5 lie close to the line of Mr. Barrus's maximum results, Nos. 8 and 9 are near the line of his average results, and No. 1 is considerably below the average line. Of the tests with culm, No. 6 is a little, and No. 7 considerably, below

the average line, while test No. 2, with one-fourth buckwheat and three-fourths culm, is far below the average line. In explanation of these varied results we find on referring to Mr. Barrus's report that in tests Nos. 1, 2, and 3 the shaking grate-bars had their air-spaces unevenly adjusted, causing an uneven distribution of air through the bed of coal. This may account to some extent for the low results of tests Nos. 1 and 2, but it does not seem to have had much effect in test No. 3, the result of which is very high. The three tests were made on three consecutive days, and possibly in test No. 1 the firing was done unskilfully, for the temperature of the gases was beyond the range of the thermometer, or over 800°, and during the whole run the flame from the coal extended into the stack and during part of the time flame could be seen issuing from the top of the stack. Overdriving of the boiler does not sufficiently account for this, for in test No. 5 with the same coal (or nearly the same) as in No. 1 and with the boiler developing as great a horse-power the temperature of the flue-gases averaged only 684°. Test No. 2, with three-fourths culm and one-fourth buckwheat, gave a result over 12 per cent below test No. 6, all culm, the boiler in the two tests being driven at the same rate. This loss of 12 per cent may have been due to mal-adjustment of the grate-bars, but it was probably partly due to the mixing of two kinds of coal, which is generally believed to give poor results with anthracite coal, the fine sizes choking up the interstices between the larger sizes, and doing this irregularly on different portions of the grate, causing irregular burning, with excess of air-supply through some portions and deficient supply through others.

Tests Nos. 1 and 5, with the same coal and the same rate of driving of the boiler, show a remarkable difference of economy, the former being over 14 per cent below the latter. The differences of the conditions of these tests which may have caused the difference in results were: (1) Larger grate-surface in No. 1 than in No. 5; (2) bad adjustment of the air-spaces in No. 1; (3) possibly, unskilled firing in No. 1. The larger grate-surface in No. 1 is not likely to have been the cause, for test No. 3 with the same large grate-surface gave practically as high a result as No. 4, with the reduced grate-surface. The difference in tests No. 1 and 5 is instructive in showing what a wide difference in results is possible in the same boiler, with the same coal and the same rate of driving, due to what may appear to be slight causes, such as difference in the air-spaces through the grate-bars or in the skill of the fireman.

TESTS OF STIRLING BOILERS AT ANTHRACITE COAL MINES.

Number of Test	1	2	3	4	5
Test for capacity or economy	Capacity.	Capacity.	Economy.	Economy.	Capacity.
Kind of coal	Buck-wheat.	Culm, ¾. Buck-wheat ½.	Buck-wheat.	Buck-wheat.	Buck-wheat.
Ash and clinker, per cent	12.0	25.9	12.0	12.0	12.6
Area of grate, sq. ft	45	45	45	38	38
Ratio of grate to heat'g surface, 1 to	31.9	31.9	31.9	37.8	37.8
Draft-suction in stack, ins. of water	.16	.16	.16	.16	.16
Draft-pressure in ash-pit, ins	1.00	1.00	0.20	0.30	1.00
Steam used to run blowers, estimated H. P	12.9	.....	7.2	6.7	13.3
Coal burned per hour per square foot of grate, lbs	29.3	14.55	13.17	14.84	28.28
Water evaporated per hour per square foot heating surface, lbs	6.04	2.74	3.61	3.33	6.06
Horse-power developed, H. P	289.3	131.3	172.8	159.6	290.2
H. P. above boiler's rating, per cent	131	5.0	38.2	27.7	132
Average temperature of flue-gases, degrees F., about	800	439	500	485	684
Water evaporated from and at 212° per pound of coal, lbs	7.563	6.910	9.955	10.075	9.310
Water evaporated from and at 212° per pound of combustible	8.594	9.325	11.324	11.449	10.052

Number of Test	6	7	8	9
Test for capacity or economy	Capacity.	Capacity.	Capacity.	Economy.
Kind of coal	Culm. No. 5.	Culm. No. 4.	Buckwheat.	Buckwheat.
Ash and clinker, per cent	15.1	20.7	15.6	13.9
Area of grate, sq. ft	45	45	47.3	47.3
Ratio of grate to heating surface, 1 to	31.9	31.9	36.5	36.5
Draft-suction in stack, ins. of water	.16	.16	.12	.10
Draft-pressure in ash-pit, ins	0.90	1.00	1.50	0.87
Steam used to run blowers, estimated H. P	8.7	12.3	13.2	
Coal burned per hour per square foot of grate, lbs	10.66	17.63	23.82	18.16
Water evaporated per hour per square foot heating surface, lbs	2.81	3.79	4.8	3.92
Horse-power developed, H. P	134.8	181.6	275.9	225.2
H. P. above boiler's rating, per cent	7.8	45.3	83.9	50.1
Average temperature of flue-gases, degrees F. about	462	543	560	524
Water evaporated from and at 212° per pound of coal, lbs	9.122	7.889	8.437	9.046
Water evaporated from and at 212° per pound of combustible	10.745	9.949	9.996	10.495

Tests Nos. 8 and 9 fall considerably below the line of tests Nos. 3, 4, and 5. These tests were made on a different boiler of the same

make, but there was probably not any difference in the details of construction of the boiler or setting which would account for the difference in results. There was, however, considerable difference in the coal, as shown by the percentage of ash and by the table of sizes. The coal used in Nos. 8 and 9 was finer in size than that used in test No. 3, 66 per cent of it going through a ¼-in. screen, while in the coal of test No. 3 only 30 per cent went through ¼-in. The coal of tests Nos. 8 and 9 was of an intermediate size between that of test No. 3 and culm, and the diagram shows that the results given by it are also intermediate between those of the other coals.

The results plotted in the diagram are the pounds of water evaporated per pound of combustible and not per pound of coal. Since the combustible of all the coals used in these tests is practically of identical quality, it might be expected that all the coals would give the same result per pound of combustible, and that results per pound of coal would correspond, except as they are influenced by different percentages of moisture and ash. The plotted results show, however, that although the combustible portion of all the coals may be identical in quality, it gives different results when it is contained in coal of different sizes. Tests Nos. 3, 4, and 5, with the largest size of buckwheat coal, give the best results, tests Nos. 8 and 9 with finer-sized buckwheat give results much lower, and tests Nos. 6 and 7, with culm, still lower results. Tests Nos. 1 and 2, both exceptionally low, may be neglected from the comparison, as they were influenced by unfavorable conditions, such as mixing of sizes and uneven adjustment of the air-spaces. The best results obtained with the large-sized buckwheat coal, also, are from 5 to 7 per cent below the best results obtained in the Centennial tests with egg coal.

A reasonable theory to account for the regular decrease in evaporation per pound of combustible as the size of the coal is made finer seems to be the following: When egg or other large-sized coal is used, a thick bed of it is carried on the grate, through which the air passes with comparative uniformity. The lumps of coal burn away slowly, from the surface; fresh coal is fired at long intervals of time, and the condition of the fire is always nearly the same. If the draft and the thickness of the bed are properly related to each other, and the boiler is well designed, the maximum economy possible with the coal may be obtained. With finer-sized coals, however, a thinner bed must be carried, relatively to the force of draft; air-holes are more likely to be formed in the bed, causing too great a supply of air to pass through

some portions while an insufficient supply is furnished to other portions. Fresh coal is fired at frequent intervals, involving frequent openings of the doors and inrush of cold air; and the fresh coal for a short time after firing, being small in size, is apt to clog the fire and obstruct the air-supply, causing the burning of the coal to carbonic oxide instead of carbonic acid. The bed of coal being thin and the draft strong, if the fireman leaves the fire unattended to for a minute or two after it is time to fire fresh coal, air-holes will form rapidly, while with egg coal a period of five minutes makes but little difference.

The results of these tests show that the efficiency of any given steam-boiler is not a constant quantity, that it varies not only with the rate of driving, but with the quality of the coal and even with the size of coal of the same quality.

Another useful lesson to be learned from these tests is in regard to the capacity. The three capacity-tests with buckwheat coal, Nos. 1, 5, and 8, gave a horse-power, respectively, 131, 132 and 84 per cent above the rated power of the boiler, and the highest economy was obtained when the boiler was driven 28 per cent above its rating. Whether any higher economy could have been obtained with this coal if the boiler had been driven at a lower rate cannot be said, for no test was made at a lower rate with buckwheat coal. The three capacity-tests with culm, Nos. 4, 6, and 7, gave respectively 5, 8, and 45 per cent above rating although the force of draft was practically the same as in the tests with buckwheat coal. It appears then that a boiler will not develop the same horse-power from culm as from buckwheat unless the grate-surface or the draft or both, are increased.

Comparative Trials on Three Two-flue Boilers with Pittsburg Coal.—These tests were made by the Shoenberger Steel Co., Pittsburg, Pa., in 1897, to determine the efficiency of the American Underfeed Stoker as compared with flat grates when applied to two-flue boilers.

The results of these tests are of interest for many reasons. The hand-fired test is fairly representative of what was every-day practice with the two-flue boiler in the Pittsburg iron-mills until the general introduction of water-tube boilers and improved furnaces and methods of firing. In this test the boiler was driven at 2.73 times its rated power, the flue-gases escaped at 816° F., and the calculated efficiency is only 43.3 per cent. In the "economy" test, so-called, with the stoker, the boiler was driven at a still higher rate of evaporation, viz., 3.05 times its rated power, although less coal was burned under it,

Grate-surface, total of three boilers, 90 sq. ft.; water-heating surface, 1225 sq. ft.; ratio of heating to grate-surface, 13.6.

	Hand-fire.	American Stoker.	
		Economy.	Capacity.
Duration, hours	8	8	7
Steam-pressure by gage, pounds	101.2	101.09	99.24
Temperature of excaping gases, °F.	816.3	735.1	828
" " feed water, °F	149.9	155.9	171.3
Size of coal	Run of Mine	River Slack	River Slack
Quantity of coal consumed, pounds	13,500	10,500	12,300
Refuse, per cent	12	9.49	
Coal per sq. ft. of grate per hour, lbs.	18.7	14.5	19.4
Total water actually evaporated, lbs.	82,160	92,140	100,917
Water per hour, equivalent from and at 212° F., pounds	11,344	12,653	15,600.3
Water per hour, per square foot heating surface, pounds	9.26	10.33	12.73
Evaporation, apparent per lb. of coal, lbs.	6.086	8.775	8.204
Evaporation, from and at 212° F., lbs.	6.72	9.640	8.877
Horse-power developed	327.8	360.7	452
Builders' rating	120	120	120
Ratio of H.P. developed to builders' rating	2.73	3.05	3.7
Heating surface per horse-power, sq. ft.	3.72	3.34	2.7
Per cent increase of capacity by the use of stoker	....	11.6	37.5
Per cent increase evaporation per lb. of coal as shown by the American Stoker over hand-firing	....	44.5	32
Efficiency, assuming the heating value per lb. combustible at 15,000 B.T.U., per cent	43.3	62.1	57.2

the temperature of the flue-gases was only 735°, and the efficiency was brought up to 62.1%. This is a very high efficiency for such a rate of driving, but it could no doubt have been brought up to 72 per cent if the rate of driving had been reduced about half and the temperature of the gases had thereby been reduced to below 500°. In the capacity-test with the stoker, still more coal per hour was burned than in the hand-fired test, and the rate of driving was the extraordinary figure of 12.73 lbs. from and at 212° per sq. ft. of heating surface per hour, or 3.7 times the rated power, yet the temperature of the flue-gases, 828°, was only a trifle higher than in the hand-fired test, while the efficiency, 57.2 per cent, was very much higher. The results of the test show the advantage gained by the short flame of very high temperature produced by the American stoker with its forced

blast, over the long smoky flame of comparatively low temperature produced in the ordinary furnace by hand-firing and natural draft.

Applying to the results of these tests the "criterion" formula given in the chapter on Efficiency of Heating Surface, page 296, viz.,

$$a = \frac{K - 4.8t}{970(1+0.1S/W)} - E_a \div \frac{23.04}{(K - 4.8t)} \frac{W}{S},$$

we obtain, taking K as 15,000

for	$W/S = 9.26$	10.33	12.73
	$E_a = 6.72$	9.64	8.877
	$a = 457$	244	234

The last two values of a, 244 and 234, represent fairly good performance. The high value of a, 457, represents poor performance, which is accounted for by incomplete combustion due to an unsuitable furnace.

Test of One of the Babcock & Wilcox Boilers for the U. S. Cruiser "Cincinnati."—In the Annual Report of the Chief of Bureau of Steam Engineering, for 1900, there is published a report of a test made on one of the new boilers built by the Babcock & Wilcox Company for the *Cincinnati,* by a board composed of Lieutenant Commander A. B. Willits and Lieutenant B. C. Bryan, U. S. Navy.

Description of Boiler and Appurtenances.—The boiler is composed entirely of wrought steel, the point of difference between it and the older type of this make of boiler being in the arrangement of baffle-plates (as shown in the sectional view, Fig. 140, p. 373, which compel the products of combustion to pass three times across the tubes before entering the uptake. The small tubes are 2 ins. outside diameter, while the bottom tube in each section or element is 4 ins. outside diameter.

BOILER DATA.

Diameter of top drum, 42 ins. (inside).
Length of top drum, 12 ft.
Tubes: Number, 526; 2 ins. outside diameter; length, 8 ft. Also 40; 4 ins. outside diameter; length, 8 ft. 5¾ ins.
Grate-surface: Length, 6 ft. 8¼ ins.; width, 9 ft. 5½ ins.; area, 63.25 sq. ft.
Grate surface reduced to 5 ft. 6 ins. length, 52 sq. ft. area, in tests Nos. 5 and 6.
Heating surface: Area, 2640 sq. ft.; ratio to grate, 41.74 : 1.
Smoke-pipe: Area, 7.876 ft.; height, 48 ft. above grate; ratio to grate, 1 : 8.03.
Weight of boiler and all fittings except uptakes and smoke-pipe:

Without water, lbs	53,304
With water, 5 ins. in glass; steam at 215 lbs., lbs.	62,802
Total weight per sq. ft. of grate-surface, lbs.	992.9
Total weight per sq. ft. of heating surface, lbs.	23.79
Weight of air-heater and ducts, lbs	5,320

Blower fan, Sturtevant; diameter, 60 ins.; driven by belt from shop engines.
Area of blower inlet, 9.62 sq. ft.; oultet, 6.89 sq. ft.
Air-heater: Two-pass; 3 in. tubes. Area of surface, 495 sq. ft.

Description and Object of Tests.—Seven tests were made in all. Six of these consisted of three pairs in which the two tests of each pair were under similar conditions in every way except that of using the air-heater, one being with and the other being without this heater, in order to define the economy due to its use. The last or seventh test was for the maximum consumption, and was made without the air-heater and with full grate. Two pairs of tests, one at a consumption of about 20 lbs. of coal and the other at about 35 lbs. of coal per square foot of grate per hour, were made with the full grate surface in use. These tests will be found in tables of results numbered 1, 2H, 3H, 4, the letter H signifying that the air-heater was in use during the tests. Tests 1 and 2H were of eight hours' duration, and tests 3H and 4 were of six hours' duration. The grate-surface was then reduced to 52 sq. ft. by a course and a half of bricks, seven courses in height, at back of furnace, and tests Nos. 5 and 6H, lasting four hours each, were made, burning about 50 lbs. of coal per sq. ft. of grate per hour. The bricks were then removed from the furnace and test No. 7, lasting three and one-third hours, was made, burning nearly 60 lbs. of coal per sq. ft. of grate per hour. The data and results of these tests will be found in the accompanying tables.

Coal and Firing.—The coal used was Pocahontas coal from Flat Top Mine. It contained considerable slate and clinkered badly. On tests Nos. 1 and 2H run-of-mine coal was used; on tests Nos. 3H, 4, 5, and 6H the coal was screened, using a screen with a 1-inch mesh. On test No. 7 the screenings from the former tests were run over a 3/8-inch mesh screen, and the coal thus screened was mixed with the screened coal used in other tests. The firing was good and very regular. Two alternate doors were fired in rapid succession. The other two sections of fires, in wake of the other two doors, were then levelled with a hoe, then sliced through the slicing door, and then coaled, the average time between coalings of the same two furnaces being from eight to ten minutes. The furnace doors were open about twenty-five seconds when coaling and about ten seconds in levelling. The coal made comparatively little smoke except when firing or working fires. The data in regard to smoke were taken by using Ringelmann charts.

Tests of a Thornycroft Boiler.—Prof. A. B. W. Kennedy, in Proc. Inst. C. E., vol. xcix p. 57, 1890, reports the results of four tests of a Thornycroft boiler. The principal figures are shown in the table on page 609.

Heating value of the coal by Prof. Kennedy's calculation from the analysis: 14,900 B.T.U. per lb.; by direct calorimetric determination, 15,450 B.T.U. per lb.

DATA OF TESTS.

Number of Test.	1	2H	3H	4	5	6H	7
Duration of test, hours	8	8	6	6	4	4	3½
Average steam-pressure by gauge, pounds	209.3	206.6	210.6	207.4	213.6	209.8	210.8
" force of draft at base of pipe, inches of water	.097	.36	.079	.127	.34	.37	1.48
" " " " in furnace, inches of water	.098	.056	.81	.967	.99	.65	.54
" " " " " ash-pit, inches of water	.25	.107	1.42	1.37	1.75	1.45	1.685
Average Temperatures: External air, degrees Fahrenheit	....	84.7	80.2	75.8	80	85	90.7
Fire-room, degrees Fahrenheit	101.5	99.5	98.2	101.8	109.3	115.4	117.0
Steam, degrees Fahrenheit	391.4	390.4	391.9	390.6	398.0	391.6	391.9
Air entering heater, degrees Fahrenheit	....	93.4	94.1	....	....	106.1	....
Air leaving heater, degrees Fahrenheit	....	206.2	235.9	....	....	259.5	....
Feed-water entering boiler, degrees Fahrenheit	101.5	106.2	103	101.8	103.3	102.0	99.7
Air entering ash-pit, degrees Fahrenheit	107.5	206.2	235.9	101.8	109.3	259.5	117
Escaping gases from boiler, degrees Fahrenheit	466	493	608.6	570.6	640.0	637	Less than 900° F.
" " " heater, degrees Fahrenheit	....	458	569	....	....	674	....
Fuel, Pocahontas coal	Run of Mine	Run of Mine	Screened	Screened	Screened	Screened	Twice screened
Weight of coal as fired, pounds*	10,345	10,600	12,925	13,517	10,600	10,046	12,600
Moisture in coal, per cent.	4.06	3.62	1.6	1.5	1.13	1.0	0.88
Weight of dry coal consumed, pounds	9,925	10,201	12,718	13,314	10,480	9,946	12,489
" combustible consumed, pounds	8,929	9,322	11,630	12,046	9,303	9,097	11,434
Refuse in dry coal, per cent.	10.03	8.60	8.55	9.52	11.23	9.54	8.45
Coal consumed per hour per square foot G.S., pounds	20.45	20.95	34.06	35.61	50.95	48.31	59.75
Combustible consumed per hour per square foot G.S., pounds	17.65	18.29	30.64	31.74	44.72	43.73	54.82
Coal per hour per square foot H.S., pounds	.490	.502	.816	.853	1.004	.592	1.432
Combustible per hour per square foot H.S., pounds	.423	.438	.734	.760	.881	.861	1.399
Quality of steam (dry steam = 100)	100	100	100	100	99.75	99.84	100
Water actually evaporated, corrected for quality of steam, pounds	93,928	100,783	113,948	118,330	90,838	86,320	102,545
Factor of evaporation	1.1657	1.1667	1.1705	1.171	1.1704	1.1715	1.173
Equivalent evaporation from and at 212° per square foot G.S., pounds per hour	216.3	232.4	351.4	365.2	511.1	486.3	570.5
Same per square foot of heating surface, pounds per hour	5.18	5.57	8.42	8.75	10.07	9.58	13.67
Water apparently evaporated, actual conditions, per pound of coal as fired, pounds	9.079	9.508	8.816	8.754	8.591	8.609	8.138
Equivalent evaporation from and at 212° per pound of coal (including moisture), lbs.	10.58	11.09	10.32	10.25	10.03	10.07	9.545
" " " " " " " dry coal, pounds	11.03	11.51	10.49	10.41	10.14	10.17	9.68
" " " " " " " combustible, pounds	12.19	12.70	11.47	11.50	11.43	11.12	10.52

* Including equivalent of wood used in lighting fires.

In tests marked H the draft-heater was in use.

Remarks and Observations.—Principal data taken every fifteen and thirty minutes. Percentage of smoke as observed, using Ringelmann smoke-charts: Test 1, No. 0 to No. 1 and as high as No. 4 when firing; test 2H, No. 0 to No. 1, with puffs of No. 4 when firing; test 3H, No. 1 to No. 2, with puffs of No. 4 when firing; test 4, No. 2 to No. 3, with puffs of No. 4 when firing; test 5, No. 1 to No. 3, with puffs of No. 4 when firing; test 6, about No. 2, with puffs of No. 4 when firing; test 7, average about No. 3, with puffs to No. 5 when firing. Kind of firing: Spreading and slicing. Average thickness of fires: Tests 1 and 2H, 6 inches; test 3H, 7 inches; tests 4, 5, 6 and 7, 6 inches. Average intervals between firings for each furnace during time fires were in normal condition: Eight to ten minutes. Average interval between times of breaking up: Eight to ten minutes. Efficiency of firemen: Expert.

ANALYSES OF WASTE GASES MADE DURING TESTS OF U. S. S. "CINCINNATI" BOILER, ELIZABETHPORT, N. J., JUNE, 1900.

Date.	Time.	Condition of fire when sample was taken.	CO^2	O	CO	Pounds dry gas per Pound Carbon.
1900.						
June 15	4.58	....	15.2	3.3	1.0	
	5.15	....	14 3	3.0	2.0	
	5.30	Just before firing....................	13.0	6.5	0.0	
	5.55	One minute after firing..................	12.5	6.7	0.8	
	6.16	Just after raking....................	14.3	3.7	1.0	16.8
	6.27	Two minutes after firing................	12.7	6.6	0.7	
	7.05	Three minutes after raking and just before firing..................	16.0	2.0	2.0	
		Average..................	14.0	4.5	1.1	
June 16	11.45	....	13.4	6.4	0.0	
	12.50	Just after firing....................	12.0	5 0	1.0	
	1.50	Just after slicing....................	12.0	6.6	0.2	19.1
	3.50	Just after slicing....................	13.2	4.8	0.7	
		Average..................	12.7	5.7	0.5	
June 18	11.25	One-half minute after firing..............	12.3	3.4	2.7	
	12.40	While slicing....................	14.2	4.0	0.1	
	12.50	Just after slicing....................	12 5	4.3	1.2	
	12.58	Just before slicing....................	13.0	4.0	3.4	17.3
	1.03	One minute after firing..................	13.5	5.4	0.2	
		Average..................	13.1	4.2	1.5	
June 19	10.10	While slicing....................	15.0	3.2	1.2	
	10.25	While slicing (all samples except 11 o'clock collected through ½-inch iron pipe),...	13.8	5.2	0.6	
	10.28	Just after raking....................	14.4	3.1	0.9	
	10.35	One minute before firing..................	13.2	5.6	0.4	
	11.00	While slicing (sample collected through glass tube)..................	13.0	5.6	0.6	18.8
	2.20	Just after raking....................	10.2	8.3	0.5	
	2.40	Just after firing....................	10.2	9.0	0.3	
		Average..................	12.8	5.7	0.6	
June 20	10.25	While slicing....................	13.5	5.7	0.0	
	11.00	While slicing....................	11.2	8.4	0.3	
	11.04	Just after firing....................	10.4	8.1	0.5	
	11.13	Two minutes before raking..............	9.2	9.9	0.0	20.6
	12.25	Just after raking....................	12.1	5.4	0.7	
	12.36	Just after raking....................	14.2	4.0	0.8	
		Average..................	11.8	6.9	0.4	
June 21	11.00	Just after raking....................	15.7	4.6	0.1	
	11.03	One minute before raking..............	13.0	6.0	0.0	
	11.13	Just after firing....................	15.4	3.0	0.6	
	11.50	Just after raking....................	13 6	5.6	0.1	17.3
	11.55	One minute before raking..............	13.0	5.3	0.4	
	11.59	Just before raking....................	16.0	4.2	0.0	
		Average..................	14 5	4.8	0.2	
June 23	11.21	Two minutes before firing..............	14.3	4.2	1.1	
	11.45	Two minutes before firing..............	11.0	9 0	0.0	
	12.38	Just before levelling and firing..........	....	......	......	
	2.26	Just after firing....................	11.8	7.9	0.4	18.6
	2.30	Just after firing....................	13.3	4.2	1.0	
	2.43	Two minutes before firing..............	14.2	3.8	1.0	
		Average..................	12.9	5.8	0.7	
June 25	10 16	Just before firing....................	15.3	4.1	1.0	
	10.21	One minute before firing..............	13.0	6.0	1.0	
	11.10	Just after levelling....................	13.7	6.6	0.3	
	11.13	Just after firing....................	14.0	5.2	0.8	18.5
	11.47	Just after firing....................	9.0	11.2	0.3	
		Average..................	13.0	6.6	0.7	

Trial No.	1	2	3	4
Heating surface, sq. ft.	1837	1837	1837	1837
Grate-surface, sq. ft.	26.2	30	30	26.2
Ratio H. S. to G. S.	70.1	61.2	61.2	70.1
Steam-pressure, lbs.	182	171	149	180
Temperature of air	69	70	60	62
Coal per sq. ft. of grate per hr., lbs.	7.74	18.60	29.80	66.80
Water per sq. ft. of H. S. per hr., lbs.	1.24	3.20	4.70	8.50
Temperature of gases in chimney	421	540	610	777
Evaporation from and at 212° per lb. of coal	13.4	12.48	12.00	10.29
Efficiency of boiler	86.8	81.4	78.2	66.6
Analyses of gases, mean:				
Carbon dioxide, CO_2	11.74	....	11.68	12.60
Carbon monoxide, CO	0.10	....	0.62	2.30
Oxygen	7.71	....	7.41	4.45
Nitrogen, by difference	80.45	....	80.29	80.65
Air used per lb. fuel, lbs.	18.14	(est. 17.8)	17.4	17.2
Heat balance:				
Heat absorbed by boiler	86.8	81.4	78.2	66.6
lost in chimney gases	10.8	15.0	16.5	20.3
lost by formation of CO	0.5	3.6	5.0	9.2
lost by radiation and unaccounted for	1.9		2.3	3.9
	100.0	100.0	100.0	100.0

Analysis of the coal:

Moisture	0.96
Ash	2.19
Carbon	87.76
Hydrogen	4.11
Oxygen, nitrogen, and sulphur	4.98
	100.00

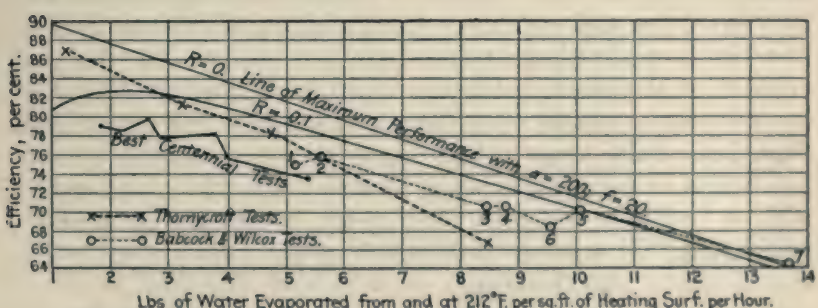

FIG. 256.—THORNYCROFT AND BABCOCK & WILCOX TESTS COMPARED.

The record of the Thornycroft test No. 1, showing 86.8 per cent efficiency, probably contains some error. The test was only of five hours' duration, and only 1006 lbs. of coal was burned in the whole test. A slight error in the measurement of coal or water, and

especially an error due to fluctuation of the water-level, would make an important error in the result at this very low rate of driving.

The relation of the efficiency to the rate of driving in the Babcock & Wilcox and the Thornycroft tests is plotted in the diagram, Fig. 256. There are also plotted, for comparison, a line representing the maximum theoretical performance of a boiler in which there is no loss by radiation, calculated by means of formula (16), page 296, with f, or pounds of dry gas per pound of carbon $= 20$, $a = 200$, $t = 300$, and $K = 15{,}750$, no account being taken of the loss of heat due to superheated steam in the chimney-gases; together with a line representing the same data but with a radiation factor of $R = 0.1$. The record of the seven best tests made at the Centennial Exhibition, taken from the diagram Fig. 77, p. 299, is also shown.

A Study of the Gas Analyses of the "Cincinnati" Tests.—The table on page 608 shows considerable variation in the composition of the gases at different periods. This is unavoidable with hand-firing of semi-bituminous coal on account of the tendency of the coal to cake shortly after firing, and thus obstructing the passage of air through the bed. With mechanical stokers and large combustion chambers, giving facilities for a thorough mixing of the air and gases, the variation would no doubt have been much less. There are some anomalies in the list of analyses, for example, at 7.05 June 15 and 11.59 June 21, the CO_2 was in both cases 16.0, an unusually high figure, but in the first case the CO and the O were both 2.0, while in the second case the O was 4.2 and the CO 0.0. At 12.58 on June 18 the CO was 3.4, while the O was 4.0, and in some other instances the CO is much higher than would be expected with the given amount of O present, indicating imperfect mixture of air and gas in the furnace. In the following table an attempt has been made to find the probable losses of heat due to imperfect combustion and to the weight of dry gas per pound of carbon for different amounts of CO_2 and of O in the gases. The weight of dry gas per pound of carbon is $\frac{11CO_2 + 8O + 7(CO + N)}{3(CO + CO_2)}$, and the heat loss is figured for an assumed temperature of the escaping gases of 500° F. above the atmospheric temperature, and a specific heat of 0.24. The loss due to imperfect combustion of carbon in B.T.U. per pound of C burned is $10{,}150 \times \frac{CO}{CO + CO_2}$, or $69.5\frac{CO}{CO + CO_2}$ per cent of 14,600 B.T.U.

LOSSES OF HEAT CORRESPONDING TO DIFFERENT GAS ANALYSES.

Range of O.	Average O.	Average CO.	Average CO_2.	Lbs. Gas per lb. C.	B.T.U. Loss Due to Gas.	Loss Due to CO.	Sum of Losses.	Excess over Ideal.	Excess Loss per cent.	No. of Cases Averaged.
4.0	4.0	3.4	13.0	15.4	1848	2101	3949	2113	14.3	1
2 to 4.0	3.4	1.4	14.4	16.0	1920	913	2833	997	6.7	12
4.1 to 6.0	5.1	0.6	13.6	17.8	2136	426	2562	726	4.9	19
6.4 to 7.9	6.8	0.34	12.7	19.4	2328	264	2592	756	5.1	7
8.1 to 11.2	9.1	0.27	10.2	23.8	2856	258	3114	1278	8.6	7
	CO_2	CO	O							
High CO_2	15.5	0.8	3.5	15.5	1860	497	2357	521	3.5	7
	16.0	2.0	2.0	14.2	1704	1127	2831	995	6.7	1
	16.0	0.0	4.2	15.3	1836	0	1836	0	0	1
	CO_2 13.5 to 14.9									
O 3.0 to 4.2	14.3	1.0	3.7	16.4	1968	660	2628	792	5.4	7
5.2 to 6.6	13.7	0.4	5.6	17.9	2148	284	2432	594	4.1	5
	CO_2 12 to 13.4									
O 3.4 to 4.8	12.9	1.8	4.1	16.9	2028	1238	3266	1430	9.7	5
5.0 to 6.7	12.8	0.4	6.0	19.0	2280	304	2584	748	5.1	13
	CO_2 below 12									
O 7.9 to 11.2	10.4	0.3	9.0	23.4	2808	284	3092	1256	8.7	8

The ideal loss is taken to be 1836 B.T.U. or that corresponding to the unusual analysis of CO_2, 16; CO, 0.0; O, 4.2. The excess of the other losses over that figure is divided by 14,800 B.T.U., the heating value of 1 lb. C, to obtain the percentage loss above the ideal.

An inspection of the above table shows that the lowest excess losses, ranging from 3.5 to 5.4 per cent, correspond to CO_2 ranging, in averaged figures, from 12.7 to 15.5, and to O ranging from 3.5 to 6.8; that higher excess losses, 6.7 to 14.3 per cent, are found both with high and with medium CO_2, 16.0 and 12.9 per cent, with low O, 2 and 4.1 per cent, and with low CO_2, 10.4, and high O, 9 per cent. It appears, therefore, that the lowest losses are always found within the narrow range of 3.5 to say 7.5 per cent O, while both high and low losses may be found with CO_2 between 12.9 and 16.0 per cent.

Tests of a Mosher Marine Boiler.—On page 612 are the principal results of four tests by George H. Barrus in 1910 of one of the Mosher boilers built for the U. S. battleships Kearsarge and Kentucky. (See Fig. 139, page 372.) The tests were each 24 hours long. The fuel was semi-bituminous coal:

The relatively low result in the third test may be partly accounted for by the low percentage of CO_2 and the high percentage of O in the chimney gases.

TESTS OF A MOSHER MARINE BOILER

Coal per sq.ft. grate per hr., lbs........	15.2	24.6	34.8	39.9
Water per sq.ft. heating surface per hr., lb	3.7	6.0	7.9	9.2
Temperature of escaping gases, deg. F...	507	568	596	625
Equiv. evap. from and at 212° per lb. comb., lbs........................	12.02	11.69	10.91	11.22
Efficiency based on combustible, %.....	75.1	72.7	67.8	69.7
Efficiency based on dry coal, %........	71.5	70.0	66.0	67.6
Gas analysis, Average:				
CO_2........................	12.4	11.7	10.6	11.5
O, %........................	6.1	7.05	8.1	7.0
CO, %........................	0.4	0.36	0.4	0.5

Tests of the "Wyoming" Boiler.—The results of six tests of a Babcock & Wilcox marine boiler built for the U. S. battleship "Wyoming" are reported in the Journal of the American Society of Naval Engineers, Nov., 1910. They correspond closely with the results obtained with the "Cincinnati" boiler ten years earlier. The most important figures are given in the table below:

TESTS OF THE "WYOMING" BOILER.

No. of test........................	1	2	3	4	5	6
Duration, hours....................	24.06	24.5	24	24	3	6
Lbs. coal per sq.ft. of grate per hr.......	15.22	24.81	35.48	41.53	70.24	43.81
Equiv. evap. from and at 212°, lbs.,						
per sq.ft. H. S. per hr................	3.88	6.43	9.03	10.52	14.76	10.52
per lb. dry coal.....................	11.42	11.61	11.38	11.38	9.45	10.75
per lb. combustible..................	12.15	12.07	11.77	11.89	10.33	11.30
Heat balance, based on combustible:						
Efficiency of boiler, %..............	74.39	73.95	72.06	72.80	63.25	69.18
Loss due to moisture in coal..........	0.07	0.06	0.06	0.09	0.07	0.07
Loss due to hydrogen in coal..........	3.27	3.34	3.44	3.45	3.46	3.37
Loss in dry chimney gases............	11.09	12.24	14.63	14.20	16.31	16.59
Loss due to incomplete combustion....	2.09	1.61	2.15	3.18	4.98	3.83
Radiation and unaccounted for........	9.08	8.80	7.66	6.28	11.93	6.96
Gas analyses, CO_2.....................	13.2	13.6	12.9	13.6	11.6	12.7
O.....................	4.2	4.7	4.5	3.9	5.07	3.0
CO.....................	0.5	0.4	0.5	0.8	1.09	0.9
Dry gas per lb. carbon................	18.41	18.07	18.80	17.54	19.40	18.46
Temperature of escaping gases, deg. F..	491	545	602	628	659	604

The coal was semi-bituminous, volatile matter 21% of the combustible; moisture, 0.86; ash, 3.61; B.T.U. per lb. combustible, 15,838.

Tests of Large Boilers (2365 H.P.) of the Delray Station of the Detroit Edison Co. (D. S. Jacobus, Trans. A. S. M. E., 1911).—The boilers described in this paper are of the Stirling type, modified as

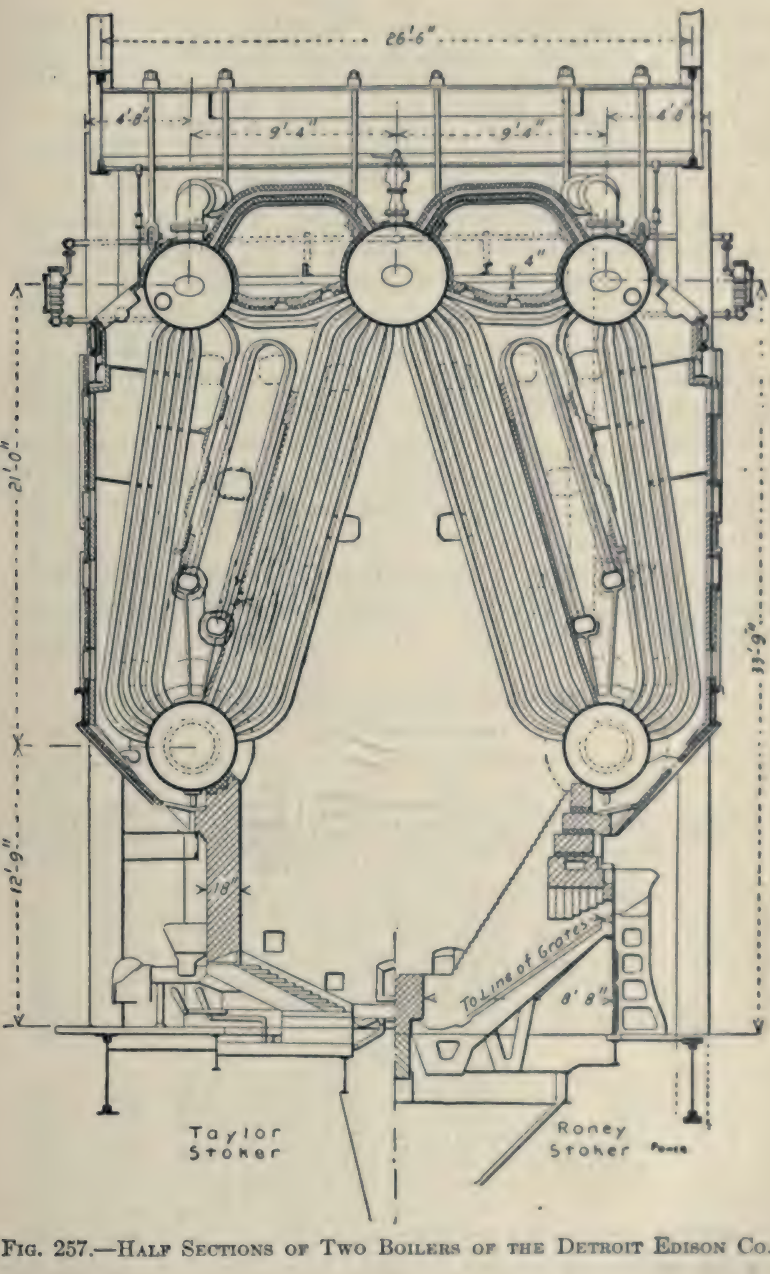

FIG. 257.—HALF SECTIONS OF TWO BOILERS OF THE DETROIT EDISON CO.

shown in Fig. 257. The cut shows a half section of two boilers, one of them being fitted with a Roney stoker and the other with a Taylor stoker. The boilers are remarkable in being by far the largest that have ever been built, and in being provided with furnaces having vastly larger combustion-space than is ordinarily used. The results also established a new record of boiler performance, which may be used as a standard of comparison with other boiler tests. The combined efficiency of boiler and grate, based on dry coal, is represented approximately by the formula $E = 80 - 1.33\ (W/S - 3)$ and the ten best out of the sixteen tests, in which the air supply was most carefully regulated gave an efficiency about 1 per cent higher. The principal results are given in the following tables. The coal used was West Virginia bituminous, containing about 35% volatile matter in the combustible and of an average heating value of about 15,250 B.T.U. per lb. combustible, except in three of the tests, Nos. 16, 17 and 18, in which the volatile matter was about 30% and the B.T.U. per pound combustible about 15,550.

Each boiler is rated at 2365 H.P. on the basis of 10 sq. ft. of heating surface per H.P. and is designed to carry a steam turbine load of 6000 kw. in the daytime and 7000 or 8000 kw. in the evening.

PRINCIPAL RESULTS OF DETROIT EDISON CO.'S TESTS.

Tests with Roney Stoker.

No. of Test.	Length, Hours.	Evap. per Sq.ft. H. S. per Hr., Lbs.	Per cent Rating.	B.T.U. per Lb. Coal.	Per cent Ash in Dry Coal.	Efficiency Based on Dry Coal.	Efficiency Based on Combustible.*	Per cent Steam used by Stoker †	Per cent Combustible in Ash.	Temp. of Flue Gases Leaving
1	25	3.63	105.0	14,362	5.98	77.84	78.80	.....	19.6	576
2	24	2.78	80.0	14,225	6.52	79.88	80.84	.....	17.9	480
3	24	3.92	113.8	14,308	7.40	77.45	78.93	0.63	24.4	542
4	30	5.26	152.4	13,756	6.54	75.78	77.48	1.58	30.8	670
5	24	3.24	94.0	13,896	6.89	81.15	82.98	1.75	31.6	483
6	24	5.20	150.7	14,037	6.13	75.28	76.65	1.45	26.7	662
16	32	3.40	98.6	14,476	9.30	80.98	83.54	1.34	34.1	460
17	16	6.67	193.3	14,493	8.24	76.73	78.37	1.39	24.6	636
18	24	6.75	195.7	13,689	9.81	75.57	77.51	1.32	23.2	694
Tests with Taylor Stoker.										
7	24	5.22	151.2	14,000	7.03	77.07	78.92	2.61	31.5	575
8	24	3.72	107.9	13,965	6.34	80.28	81.72	2.44	27.1	493
9	50	5.62	162.8	13,998	6.75	77.85	79.38	2.87	31.3	574
10	48	3.22	92.9	14,188	9.90	77.90	81.78	2.63	27.2	487
11	26.5	7.29	211.3	14,061	9.55	75.84	77.71	3.41	36.1	651
12	48	4.18	121.3	14,010	8.09	79.24	80.82	2.57	27.6	535
14	24	6.40	185.5	14,272	8.71	76.42	78.60	2.95	28.8	647

* Approximate; calculated from the efficiency based on dry coal by adding 80% of the heat loss due to carbon in ash, taken from the heat balance.

† By stoker engines and steam jets in the Roney tests and by engines driving stokers in steam turbine driving fan in the Taylor tests.

HEAT BALANCE, PERCENTAGES OF TOTAL HEAT IN COAL.

Flue Gas Analyses and Temperature Taken in Breeching.

Roney Stoker Tests.

No. of Test.	Absorbed by Boiler.	Moisture in Coal.	Hydrogen in Coal.	Heat to Chimney			Carbon Monoxide.	Carbon in Ash.	Radiation, etc.
				Heat to Chimney.	Moisture in Air.	Total.			
1	77.84	0.18	4.55	13.56	0.37	13.93	0.23	1.20	2.07
2	79.88	0.16	4.36	9.15	0.26	9.41	0.42	1.20	4.57
3	77.45	0.15	4.48	11.39	0.32	11.71	0.74	1.85	3.62
4	75.78	0.17	4.49	12.79	0.36	13.15	1.95	2.13	2.33
5	81.15	0.16	4.29	9.11	0.20	9.31	1.29	2.29	1.51
6	75.28	0.21	4.74	13.17	0.36	13.53	1.16	1.71	3.37
16	80.98	0.22	4.18	8.94	0.19	9.13	0.27	3.20	2.02
17	76.73	0.22	4.47	12.47	0.28	12.75	0.74	2.05	3.04
18	75.57	0.21	4.64	14.34	0.27	14.61	0.62	2.42	1.93
								Average	2.72
Taylor Stoker Tests.									
7	77.07	0.18	4.58	11.54	0.28	11.82	1.61	2.31	2.43
8	80.28	0.17	4.28	10.12	0.24	10.36	0.40	1.80	2.71
9	77.85	0.20	4.31	11.21	0.25	11.46	0.44	2.20	3.54
10	77.90	0.18	4.34	11.35	0.26	11.61	0.27	2.77	2.93
11	75.84	0.18	4.47	11.91	0.35	12.26	0.59	3.58	3.08
12	79.24	0.18	4.46	11.05	0.21	11.26	0.16	2.32	2.38
14	76.42	0.18	4.51	13.15	0.27	13.42	0.31	2.57	2.59
								Average	2.81

FLUE GAS ANALYSES.

Roney Stoker.

No. of Test.	Bottom of Last Pass.			Top of Last Pass.			In Flue.		
	CO_2.	O.	CO.	CO_2.	O.	CO.	CO_2.	O.	CO.
1	13.22	5.29	0.00	12.41	6.48	0.00	11.95	7.55	0.05
2	15.18	3.00	0.06	14.31	4.01	0.07	14.33	4.54	0.11
3	14.50	3.50	0.09	12.25	6.12	0.02	13.05	6.46	0.18
4	14.45	3.44	0.35	13.51	4.68	0.20	14.74	3.96	0.54
5	15.65	2.27	0.25	14.68	3.40	0.20	14.40	4.54	0.35
6	14.77	3.23	0.20	14.28	3.87	0.15	14.66	4.23	0.31
16	13.82	4.88	0.00	13.82	4.88	0.00	13.55	5.92	0.07
17	14.25	4.06	0.40	13.98	4.48	0.25	14.69	4.55	0.20
18	.....	....	....	.....	....	....	14.16	5.04	0.16
Taylor Stokers.									
7	15.46	2.83	0.08	12.16	6.64	0.00	14.00	5.50	0.42
8	15.04	3.35	0.02	12.74	5.83	0.01	13.69	5.82	0.10
9	15.84	2.40	0.03	13.88	4.62	0.02	14.74	4.57	0.12
10	13.14	5.59	0.00	11.91	6.96	0.00	11.86	7.96	0.06
11	15.25	2.92	0.25	14.62	3.30	0.21	15.45	3.86	0.17
12	14.83	3.59	0.00	13.28	5.35	0.00	13.79	5.73	0.04
13	15.43	2.96	0.09	13.85	4.65	0.37	15.17	3.90	0.19
14	15.07	3.33	0.17	12.90	5.67	0.06	14.20	5.08	0.08
15	11.70	7.16	0.12	10.35	8.79	0.01	10.83	8.93	0.09

Some data not included in the tables are: Grate surface, measured from the front of the furnace to the rear of the dumping grates, Roney stoker, 446 sq. ft., Taylor stoker, 405 sq. ft. Steam pressure, by gauge, 192 to 207 lbs. Superheat 102° to 168°. Horse power developed 1903 to 5083.

The relation of the efficiency of boiler and grate to the rate of driving is plotted in Fig. 258. Ten of the best tests come very near

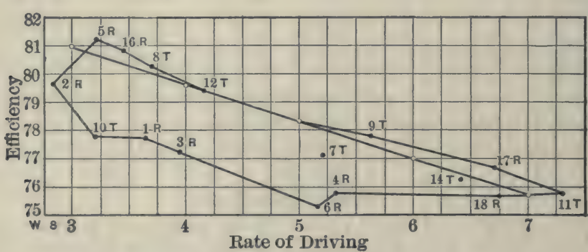

FIG. 258.—RESULTS OF THE DETROIT TESTS

to the straight line whose equation is $81 - 1.33\ (W/S - 3)$ and the other six fall considerably below the line. The difference between the efficiency obtained in each test and that calculated from this formula is given in the table below:

TEN BEST RESULTS.
(*R*, Roney; *T*, Taylor.)

No. of Test	5*R*	16*R*	8*T*	12*T*	7*T*	9*T*	14*T*	17*R*	18*R*	11*T*
W/S.	3.24	3.40	3.72	4.18	5.22	5.62	6.40	6.67	6.75	7.29
E by formula.	80.68	80.47	80.04	79.43	78.04	77.56	76.47	76.11	76.00	75.28
E by test.	81.15	80.98	80.28	79.24	77.07	77.85	76.42	76.73	75.57	75.84
Difference.	+0.47	+0.51	+0.24	−0.19	−0.97	+0.29	−0.05	+0.62	−0.43	+0.56

SIX LOWER RESULTS.

No. of Test.	2*R*	10*T*	1*R*	3*R*	6*R*	4*R*
W/S.	2.78	3.22	3.63	3.92	5.20	5.26
E by formula.	81.29	80.71	80.16	79.77	78.07	77.99
E by test.	79.88	77.90	77.84	77.45	75.28	75.78
Difference.	−1.41	−2.81	−2.32	−2.32	−2.79	−2.21

The lower results may be accounted for by too great or too little air supply, as shown by the oxygen in the flue gases. The ten high results were obtained with O from 3.86 to 5.82%. Of the six low results three were obtained with high O, 6.46 to 7.96, and three with

low O, 3.96 to 4.54. To obtain the highest efficiency it appears that O must be below 6, but if it is below 4.5 the efficiency may be low on account of imperfect combustion.

The reasons for the high efficiency obtained in the Detroit tests as compared with all previous tests are: 1. The great size of the boiler, diminishing the radiation loss. 2. The use of mechanical stokers, insuring uniform feeding of the coal and the avoidance of loss of heat from the opening of fire-doors. 3. The enormous size of the combustion space, making possible, with proper regulation of the thickness of coal bed and of the air-supply, the complete burning of the volatile

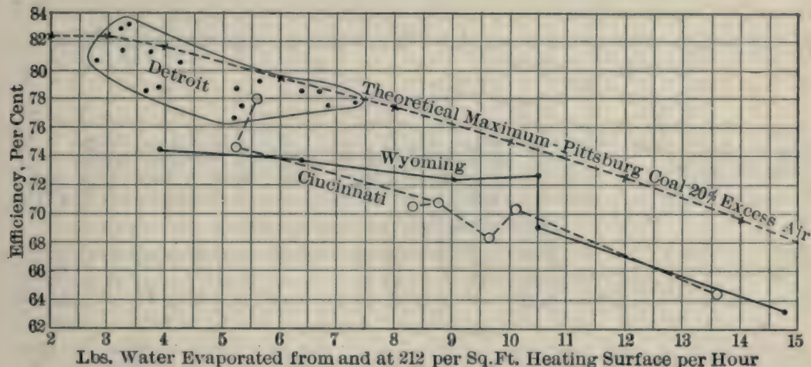

FIG. 259.—RELATION OF EFFICIENCY TO RATE OF DRIVING.

gases before they reach the heating surface. 4. The great care given to the regulation of the air-supply, in accordance with the indications of gas analyses.

The greatest source of probable error in the results is in the sampling and analyses of the coal. The sampling and the analyses were done by two laboratories and their results averaged. Individual analyses showed some erratic variations, indicating that the average analysis may have an error of 1 per cent, and that the error in some of the tests may have been as high as 2 per cent.

Comparison of Three High Records.—In Fig. 259, the results of the Detroit, the Cincinnati, and the Wyoming tests are plotted together with the curve of the theoretical maximum efficiency obtained with Pittsburgh coal, with 20 per cent excess air supply as calculated by formula 18 of Chapter IX. The Detroit tests approach so near to this theoretical maximum that it is evident that but little margin remains for improving the efficiency of properly built and properly managed

boilers and furnaces, except such as may be made by the use of economizers. The difference between the Wyoming and Cincinnati tests and the theoretical maximum are accounted for by the irregularities due to hand-firing, and to the restricted volume of the combustion chamber, which was insufficient for complete burning of the gases. A large part of the unaccounted-for loss in the heat balance was undoubtedly due to the escape of unburned hydrocarbons.

In Fig. 259, the efficiencies plotted are all based on combustible. Those of the Detroit tests are represented by the formula $E = 82 - 1.33\ (W/S - 3)$, and those of the Wyoming and Cincinnati tests by $E = 79.5 - 1.4\ (W/S - 3)$. The following table shows the variation of the actual efficiencies from those computed by the two formulae:

"DETROIT" TESTS, RONEY STOKER.

Rate of driving, W/S....	2.78	3.24	3.40	3.63	3.92	5.20	5.26	6.67	6.75
Efficiency, actual........	80.84	82.98	83.54	78.80	78.93	76.65	77.48	78.37	77.51
" from formula..	82.29	81.68	81.47	81.16	80.77	79.07	78.99	77.11	77.00
Difference..............	−1.45	+1.30	+2.07	−2.36	−1.85	−2.42	−1.51	+1.26	+0.51

"DETROIT" TESTS, TAYLOR STOKER.

W/S..................	3.22	3.72	4.18	5.22	5.62	6.40	7.29
Efficiency, actual........	81.78	81.72	80.82	78.92	79.38	78.60	77.71
" from formula..	81.71	81.04	80.43	79.04	78.51	77.47	76.28
Difference..............	+0.07	+0.68	+0.39	−0.12	+0.87	+1.13	+1.43

"CINCINNATI" TESTS.

W/S..................	5.18	5.57	8.42	8.75	9.58	10.07	13.67
Efficiency, actual........	74.80	77.90	70.46	70.60	68.20	70.10	64.50
" from formula..	76.45	75.90	71.91	71.45	70.21	69.60	65.63
Difference..............	−1.65	+2.00	−1.51	−0.85	−2.01	+0.50	−1.13

"WYOMING" TESTS.

W/S..................	3.88	6.43	9.03	10.52	10.52	14.76
Efficiency, actual........	74.39	73.95	72.06	72.80	69.18	63.25
" from formula..	78.37	74.70	71.06	68.97	68.97	63.04
Difference..............	−3.98	−0.75	+1.00	+3.83	+0.21	+0.21

Tests of a Locomotive.—W. F. M. Goss, in Bulletin 402 of the U. S. Geological Survey, 1909, describes a series of 18 tests made at the locomotive-testing laboratory of Purdee University to determine the efficiency of a locomotive with two kinds of coal at different rates of driving. The boiler had 111 2-inch and 16 5-inch tubes; heating surface, fire-box, 126 sq. ft., water side of tubes, 897 sq. ft., outside of superheater tubes, 193 sq. ft., total 1216 sq. ft.; grate surface 17.7 sq. ft. The two coals were: A, a bituminous, with moisture 1.89%, ash 8.46%, and 35.6% volatile matter in the combustible, and B, semi-bituminous, moisture 3.10%, ash 8.92%, volatile 17.1%. Heating value per pound of combustible, A, 15,372; B, 15,802 B.T.U. per lb. The principal results are given in the table on page 620. Fig. 260 shows a plotting of the efficiency based on combustible consumed, which

is figured by subtracting from the combustible fired (that is the coal less the moisture and ash determined by analysis) the combustible in the ash an refuse from the grate and in the stack and flue cinders. This efficiency is very much higher than the efficiency of the boiler and grate, based on the combustible fired, on account of the large loss of fuel in the cinders. The most notable result of this series of tests is the great falling off in efficiency and the large "unaccounted for loss" in the case of the semi-bituminous coal. The report says:

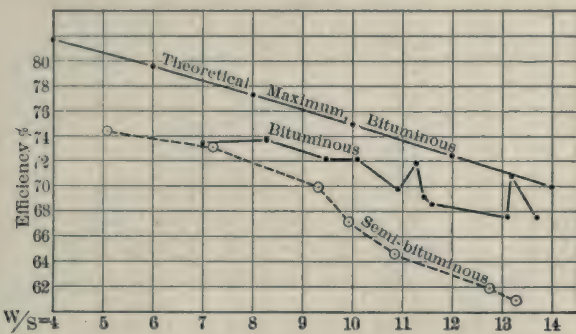

FIG. 260.—RESULTS OF LOCOMOTIVE TESTS.

"The cinders from coal B have more than double the weight and each pound has nearly double the heating value of those from coal A, a result doubtless due in part to the large percentage of fine material in coal B, and to the absence of such material in coal A."

AVERAGED HEAT BALANCE FOR LOCOMOTIVE TEST.

(Percentages of total heat available.)

Absorbed by the water in the boiler	52	
Absorbed by the steam in the superheater	5	
Absorbed by steam in the boiler and superheater		57
Lost in vaporizing moisture in the coal		5
Lost through the discharge of CO		1
Lost through the high temperature of escaping gases, the products of combustion		14
Lost through unconsumed fuel in the form of front-end cinders		3
Lost through unconsumed fuel in the form of cinders or sparks passed out of the stack		9
Lost through unconsumed fuel in the ash		4
Lost through radiation, leakage of steam and water, etc.		7
		100

RESULTS OF LOCOMOTIVE TESTS.

No. of Test.	Duration, Hours.	Dry Coal per Sq.ft. Grate per Hr., Lbs.	Water Evap. from and at 212° per Sq.ft. H.S. per Hr.	Equiv. Evap. per Lb. Dry Coal Fired.	Equiv. Evap. per Lb. Combustible Consumed.	Efficiency, Boiler and Grate.	Efficiency of Boiler Based on Comb. Consumed.	Analysis of Gases.			Dry Gas per Lb. C Burned.	Temperature in Smoke-box.
								CO_2.	O.	CO.		
1	1.03	114	13.69	8.56	10.89	58.7	67.60	14.63	2.98	1.06	16.18	815
2	1.67	108	13.08	8.67	10.92	59.3	67.65	13.95	3.81	.99	16.95	798
3	2.00	94	11.51	8.79	11.07	60.1	68.83	14.11	4.32	.77	17.04	775
4	2.00	69	9.43	9.75	11.59	66.4	72.36	14.27	4.05	.12	17.63	726
5	2.50	101	13.18	9.34	11.55	63.2	70.80	13.90	3.87	.40	17.70	824
6*	0.83	99	10.82	7.82	11.11	53.9	66.55	13.59	5.16	.10	18.49	778
7	2.00	91	10.89	8.55	11.10	61.4	69.85	14.63	3.01	1.39	15.85	747
8	2.50	91	11.47	9.04	11.03	62.3	69.27	13.64	4.72	.27	18.20	787
9*	2.50	53	7.16	9.72	12.19	65.7	73.33	11.70	7.40	.01	21.47	661
10	2.50	83	11.26	9.75	11.57	66.2	71.97	13.48	5.14	.31	18.35	764
11	2.50	75	10.07	9.55	11.55	66.2	72.23	12.85	5.81	.35	19.12	722
12	2.50	46	7.02	10.06	11.70	69.0	73.45	12.47	6.11	.29	19.75	670
13*	1.50	134	13.30	7.10	10.30	46.7	60.92	12.05	6.34	.27	20.41	782
14*	1.50	131	12.77	6.98	10.33	47.4	61.74	11.82	6.77	.16	21.01	772
15*	2.00	89	9.90	7.95	11.27	53.6	67.21	11.57	7.15	.15	21.43	702
16*	2.50	74	9.30	8.96	11.56	60.0	69.79	11.99	7.43	.04	20.92	692
17	2.50	58	8.25	10.16	11.87	69.7	73.77	12.20	6.15	.19	20.31	676
18*	2.50	36	5.12	10.23	12.38	68.1	74.64	10.81	8.82	.11	22.96	579

HEAT BALANCE (BASED ON COMBUSTIBLE FIRED).

No. of Test.	Percentage of Heat.									
	Absorbed by Boiler and Superheater.	Due to H_2O in Coal.	Due to H_2O in Air.	Due to H_2O Formed by H in Coal.	Due to Escaping Gases.	Due to Incomplete Combustion.	Due to Front End Cinders.	Due to Stack Cinders.	Due to Refuse in Ash Pan.	Unaccounted for.
1	58.75	0.16	0.46	4.11	12.83	3.74	8.02	0.92	4.15	6.86
2	59.28	.15	.20	4.05	13.35	3.67	7.94	.95	3.48	6.93
3	60.08	.16	.53	4.11	13.31	2.93	5.75	.89	6.06	6.17
4	66.37	.27	.25	4.48	13.58	.47	2.81	1.34	4.13	6.30
5	63.16	.18	.40	4.17	14.93	1.56	5.90	1.11	3.78	4.81
6*	53.90	.22	.35	3.45	13.32	.42	11.96	1.80	5.23	9.37
7	61.34	.19	.49	4.41	12.86	4.90	4.95	1.35	5.88	4.63
8	62.34	.15	.31	4.16	14.98	1.09	4.08	.81	5.12	6.96
9*	65.70	.35	.37	3.41	15.07	.05	4.22	1.53	4.65	4.65
10	66.16	.16	.27	4.24	15.18	1.27	3.64	.73	3.70	4.65
11	66.25	.22	.27	4.21	14.79	1.49	3.02	1.33	3.93	4.49
12	69.12	.18	.37	3.80	14.11	1.27	1.16	.99	3.74	5.26
13*	46.72	.28	.35	3.51	13.98	1.26	16.74	3.76	2.81	10.59
14*	47.45	.34	.28	3.61	14.46	.78	15.10	5.20	2.84	9.94
15*	53.67	.27	.27	3.46	13.78	.73	12.09	2.06	6.00	7.67
16*	59.97	.26	.27	3.42	14.56	.19	7.82	2.03	4.22	7.26
17	69.73	.22	.38	3.89	14.58	.85	1.76	.86	2.86	4.87
18*	68.14	.35	.29	3.06	13.58	.56	2.52	1.10	5.09	5.31

* Semi-bituminous coal.

Following is an extract from the general conclusions of the report:

There were in 1906, on the railroads of the United States, 51,000 locomotives. It is estimated that these locomotives consumed during the year not less than 90,000,000 tons of fuel, which is more than one-fifth of all the coal, anthracite and bituminous, mined in the country during the same period. The coal thus used cost the railroads $170,-500,000.* That wastes occur in the use of fuel in locomotive service is a matter which is well understood by all who have given serious attention to the subject, and the tests whose results are here presented show some of the channels through which these wastes occur. These results are perhaps more favorable to economy than those attained by the average locomotive of the country, as the coal used in the tests was of superior quality, the type of locomotive employed was better than the average, and the standards observed in the maintenance of the locomotive were more exacting. But so far as they apply, the results may be accepted as fairly representative of general locomotive practice. They apply, however, only when the locomotive is running under constant conditions of operation. They do not include the incidental expenditures of fuel which are involved in the starting of fires, in the switching of engines, and in the maintenance of steam pressure while the locomotive is standing, nor do they include a measure of the heat losses occasioned by the discharge of steam through the safety valve. Observations on several representative railroads have indicated that not less than 20 per cent of the total fuel supplied to locomotives performs no function in moving trains forward. It disappears in the incidental ways just mentioned or remains in the fire box at the end of the run. The fuel consumption accounted for by the heat balance is, therefore, but 80 per cent of the total consumed by the average locomotive in service. Applied on this basis to the total consumption of coal for the country, the heat balance may be converted into terms of tons of coal as follows:

SUMMARY OF RESULTS OBTAINED FROM FUEL BURNED IN LOCOMOTIVES.

	Tons.
1. Consumed in starting fires, in moving the locomotive to its train, in backing trains into or out of sidings, in making good safety-valve and leakage losses, and in keeping the locomotive hot while standing (estimated)	18,000,000
2. Utilized, that is, represented by heat transmitted to water to be vaporized	41,040,000
3. Required to evaporate moisture contained by the coal	3,600,000
4. Lost through incomplete combustion of gases	720,000
5. Lost through heat of gases discharged from stack	10,080,000
6. Lost through cinders and sparks	8,640,000
7. Lost through unconsumed fuel in the ash	2,880,000
8. Lost through radiation, leakage of steam and water, etc	5,040,000
	90,000,000

* Rept. Interstate Commerce Commission, 1906.

It is apparent from this exhibit that the utilization of fuel in locomotive service is a problem of large proportions, and that if even a small saving could be made by all or a large proportion of the locomotives of the country it would constitute an important factor in the conservation of the nation's fuel supply.

Application of the Criterion Formula for a_1 to the "Cincinnati," "Wyoming," Detroit and Locomotive Tests.—On page 319 will be found tables giving the values of a_1 for these tests, computed from formula (18) page 316. Fig. 261 is a plotting of these values.

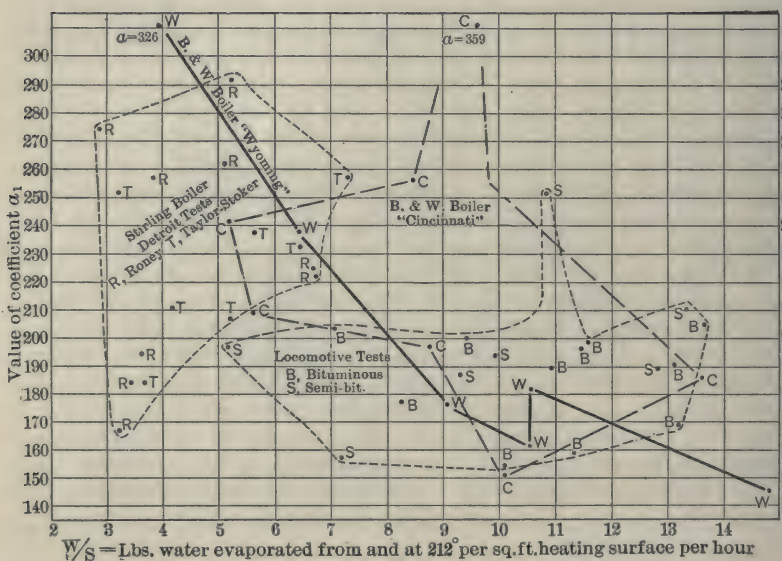

FIG. 261.—VALUES OF THE COEFFICIENT a_1.

The average value of a_1 for the 47 tests is 211. Omitting four high values, above 270, the average is 201. The figures in the table and the chart plotted from do not indicate that there is any definite relation between the value of a_1 and either the type of the boiler or the rate of driving. The four exceptionally high figures, above 270, are found at rates of driving ranging from 2.78 to 9.58, and the eight lowest figures, below 170, are found at rates of driving from 3.22 to 14.76. Of the 47 tests, 42 give values of a_1 between 150 and 270, averaging 202, and 37 give values between 160 and 260, averaging 206.

The large range of variation appears to be due to errors of measurement of the coal or water, or of sampling and analysis of the coal and

the flue gases. The conclusion drawn from this investigation is that with any form of boiler and with any rate of driving, the average value of the coefficient a is about 200, provided the efficiency is not reduced by excessive radiation, leaks of air into the setting, short-circuiting of the gases, or foulness of the heating surface from scale or soot, and that if in any test these causes of high values of a_1 are avoided, and the computation shows a value of a below 150 or above 250, errors in measurement, sampling or analysis are the probable cause of the variation.

Range of Results Obtained from Anthracite Coal.—Selecting the

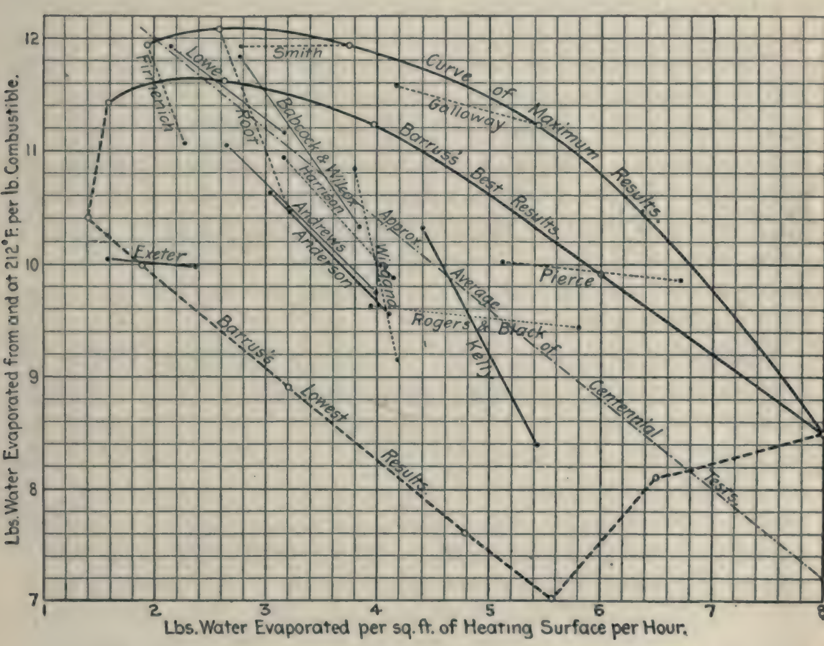

FIG. 262.—RESULTS OF TESTS WITH ANTHRACITE COAL.

highest results obtained at different rates of driving with anthracite coal in the Centennial tests in 1876,* and the highest results with anthracite reported by Mr. Barrus in his book on Boiler Tests, the two curves in the diagram, Fig. 262, have been plotted, showing the maximum results which may be expected with anthracite coal, the

* Reports and Awards Group XX, International Exhibition, Phila., 1876; also Clark on the Steam-engine, vol. i. p. 253.

first under exceptional conditions, such as obtained in the Centennial tests, and the second under the best conditions of ordinary practice (Trans. Am. Soc. M. E., vol. xviii. p. 354). From these curves the following figures are obtained:

Lbs. water evaporated from and at 212° per sq. ft. heating surface per hour:	2	2.5	3	3.5	4	4.5	5	6	7	8
Lbs. water evaporated from and at 212° per lb. combustible:										
Centennial....	12.	12.1	12.1	12.	11.85	11.7	11.45	10.8	9.8	8.5
Barrus.......	11.65	11.65	11.55	11.4	11.2	10.95	10.6	9.9	9.2	8.5
Avg. Cent'l...	12.0	11.6	11.2	10.8	10.4	10.0	9.6	8.8	8.0	7.2

The figures in the last line are taken from a straight line drawn as nearly as possible through the average of the plotting of all the Centennial tests. The poorest results are far below these figures. It is evident that no formula can be constructed that will express the relation of economy to rate of driving as well as do the three lines of figures given above. The great width of the field between the highest and lowest curves on the diagram is an indication of the great saving of fuel that may be made by bringing poor boiler performance up to the level of the best.

Tests with Anthracite at the Centennial Exhibition, 1876.—The table on page 625 gives the principal results obtained in the economy trials at the Centennial Exhibition, together with the capacity and economy figures of the capacity trials for comparison, and the results are plotted on the diagram, Fig. 262. Some of the results are also plotted on the diagram, Fig. 77, page 299, for comparison with theoretical performance under certain assumed conditions. Of the fourteen boilers tested, illustrations of seven have already been given, as follows: Root, page 363, Firmenich, page 359; Babcock & Wilcox, page 361; Galloway, page 343; Wiegand page 354; Kelly, page 355; Rogers and Black, page 357. The Root boiler used in the test differed from the one on page 363 in not having the series of horizontal longitudinal steam- and water-drums, a single transverse drum being used instead. The other seven boilers are illustrated and briefly described below.

The Lowe boiler, Fig. 263, is an ordinary cylindrical tubular boiler $4 \times 18\frac{1}{2}$ ft. with forty-six tubes 3 ins. $\times$ 15 ft., with a chamber or connection in the front end of the boiler, the rear of which forms the front tube-sheet. The bridge-wall back of the grate is extended

up to the shell. The heated gases pass through side openings through the water-space into the front chamber, thence through the tubes to the rear of the boiler, then through a return-flue along the lower half of the shell to the rear of the bridge-wall, when they rise through two side flues, and circulating around the upper half of the shell and a superheating drum, escape to the uptake.

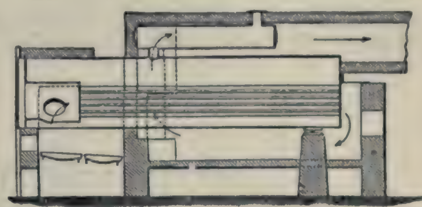

FIG. 263.—THE LOWE BOILER.

Name of Boiler.	Economy Tests.									Capacity Tests.		
	Ratio Water-heating Surface to Grate-surface.	Coal Burned per sq. ft. Grate per Hour.	Per cent Ash and Refuse.	Water Evap. from and at 212° per sq. ft. H.S. per Hour.	Water Evap. from and at 212° p. lb. Comb'ble cor. for Quality of Steam.	Temperature in Uptake.	Moisture in Steam.	Superheating of Steam.	Horse-power.	Horse-power.	Water Evap. from and at 212° per lb. Combustible.	Water Evap. from and at 212° per sq. ft. H.S. per Hour.
		lbs.	p.ct.	lbs.	lbs.	deg.	p.ct.	deg.	H.P.	H. P.	lbs.	lbs.
Root	34.6	9.1	10.4	2.59	12.094	393	...	41.4	119.8	148.6	10.441	3.21
Firmenich	64.3	12.0	10.4	1.93	11.988	415	...	32.6	57.8	68.4	11.064	2.29
Lowe	30.6	6.8	11.3	2.15	11.923	333	...	9.4	47.0	69.3	11.163	3.17
Smith	45.8	12.1	11.1	2.79	11.906	411	1.3	...	99.8	125.0	11.925	3.74
Babcock & Wilcox	37.7	10.0	11.0	2.79	11.822	296	2.7	...	135.6	186.6	10.330	3.84
Galloway	23.7	9.6	11.1	4.18	11.583	303	...	1.4	103.3	133.8	11.216	5.41
do semi-bit. coal	23.7	7.9	8.8	3.68	12.125	325	0.3	...	90.9	125.1	11.609	5.06
Andrews	15.6	8.0	10.3	2.67	11.039	420	...	71.7	42.6	58.7	9.745	4.00
Harrison	27.3	12.4	8.5	3.16	10.930	517	0.9	...	82.4	108.4	9.889	4.15
Wiegand	30.7	12.3	9.5	3.80	10.834	524	...	20.5	147.5	162.8	9.145	4.19
Anderson	17.5	9.7	9.3	3.03	10.618	417	...	15.7	98.0	132.8	9.568	4.11
Kelly	20.9	10.8	9.0	4.40	10.312	...	5.6	...	81.0	99.9	8.397	5.43
Exeter	33.5	9.3	11.4	1.59	10.041	430	4.2	...	72.1	108.0	9.974	2.38
Pierce	14.0	8.0	11.0	5.11	10.021	374	5.2	...	51.7	67.8	9.865	6.70
Rogers & Black	19.0	8.6	9.9	3.94	9.613	572	2.1	...	45.7	67.2	9.429	5.80
Averages	..	..	..	3.19	11.123	..	...	...	85.0	110.8	10.251	4.23

The Smith boiler, Fig. 264, is an ordinary return-tubular boiler, supplied with additional heating surface in the setting. From the hollow cast-iron bridge-wall a number of pipes run horizontally under and back of the boiler and connect to short vertical tubes screwed into a larger horizontal pipe located back of the shell and connected thereto. In addition to the above, two cast-iron pipes run along either side of and below the grate and are connected with the water-space in the shell. In the latter are attached on either side a series of vertical conical castings, bulb-shaped at their tops, with a small wrought-iron pipe in each as an outlet for steam, and the several small steam-pipes are connected together and to the steam-space of the main shell.

The Andrews boiler, Fig. 265, is of the double marine tubular type with internal furnace and external sheet-iron connections for directing the products of combustion from the lower set of tubes to the upper. The shell is rectangular with a semi-cylindrical top.

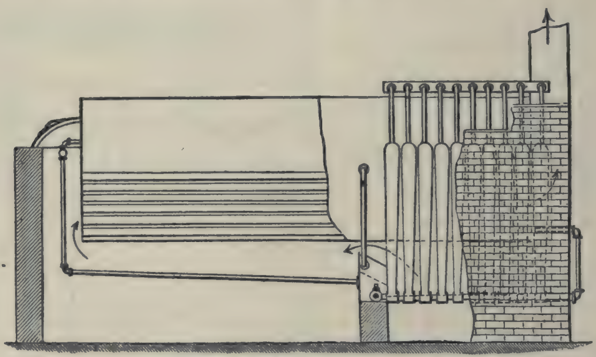

FIG 264.—THE SMITH BOILER.

The Harrison boiler, Fig. 266, consists of sections of hollow cast-iron spheres, 8 ins. diameter, with curved necks, cast in groups of two and four and held together by bolts extending through the spheres and necks the entire length of the sections. The sections are set side by side at the angle shown.

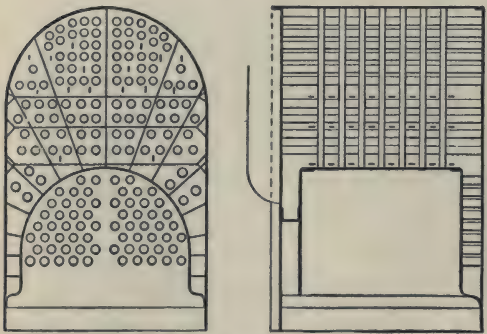

FIG. 265.—THE ANDREWS BOILER.

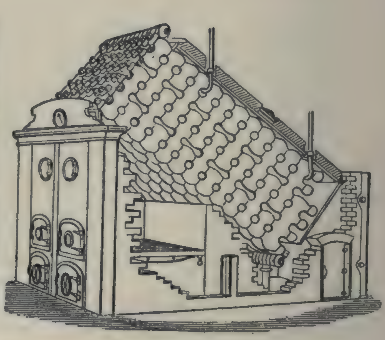

FIG. 266.—THE HARRISON BOILER.

The Anderson boiler, Fig. 267, is composed of sections, each containing nine wrought-iron tubes 3 ins. diameter and 10 ft. long, which are nearly horizontal and arranged in a vertical row. The four lower tubes are secured at their front ends to a cast-iron chamber and rise a little from front to rear. The front ends of the five upper tubes are similarly attached to an upper chamber, and slope a little

from front to rear. The rear ends of all the tubes are united by a manifold. The lower front chambers are connected at their lower ends and the upper front chambers at their upper ends. A horizontal partition is placed above the four lower tubes, so as to compel the

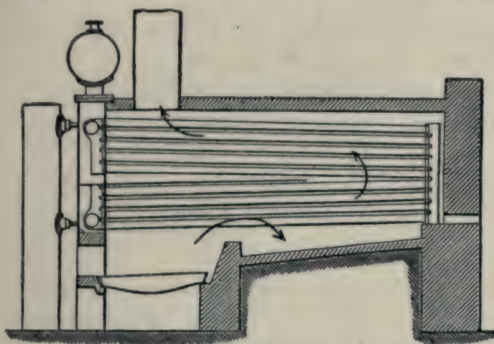

Fig. 267.—The Anderson Boiler.

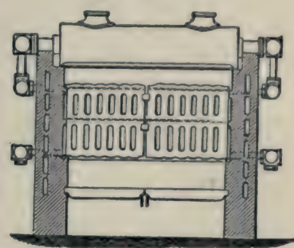

Fig. 268.—The Exeter Boiler.

gases to flow first along the four lower tubes and then along the five upper tubes.

The Exeter boiler, Fig. 268, consists of hollow, rectangular, cast-iron, slab-shaped sections set transversely, with twelve oblong openings in two horizontal flues through each section. Twenty-seven such sections are placed one in the rear of the other and connected through short side pipes to one steam- and one feed-pipe thus forming a complete boiler. Two of these boilers are placed side by side over one grate. The gases from the grate pass to the rear of the boiler through the lower row of passages and return through the upper rows.

The Pierce boiler, Fig. 269, consists of a flat-ended cylinder directly above the fire-grate, revolving on trunnions. The heated gases envelop the cylinder and enter one end of an annular row of tubes in the shell, and after passing through them return through another row of tubes concentric with the first and thence escape to the chimney. Cups are secured around the tubes of the outer row, to catch the water whenever the tube is lifted above the water-line by the revolving of the shell, and thus prevent overheating of these tubes and

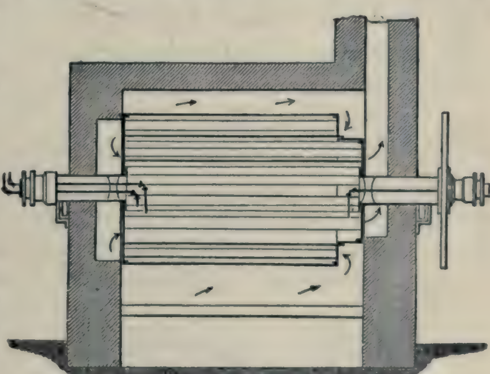

Fig. 269.—The Pierce Boiler.

of the shell. The feed-water is introduced through one trunnion and steam is taken out through the other.

Some of the conclusions which may be drawn from the results of the Centennial tests are the following:

1. The high results obtained by the first six boilers on the list, page 625, viz.: the Root, Firmenich, Lowe, Smith, Babcock & Wilcox, and Galloway boilers, constitute a standard of performance which has not been excelled since 1876 in any properly authenticated series of tests with anthracite coal.

2. These high figures being obtained with boilers of widely different types, it is evident that economy of fuel does not depend to any great extent on the type of boiler.

3. The low results obtained in the tests of all the other boilers are not explained by their design, or by anything in the record of their tests. Of the possible causes of low performance are excessive air-supply, especially at the higher rates of driving; short-circuiting of the gases; excessive loss by radiation. The lack of analyses of the chimney-gases prevents the drawing of any definite conclusions in regard to the air-supply.

4. The most important conclusion is that at any given rate of driving the difference in economy between the best and the poorest results may be as much as 30 per cent, even under test conditions with supposedly expert firing, when the boiler is hand-fired and the air-supply is not controlled in accord with the results of gas analyses or with the record of a CO_2 indicator.

Commenting on the results plotted in Fig. 262 the author many years ago made the statement that the relation between the economy and the rate of driving of a boiler was not expressed by any formula or curve, but by a broad field whose upper boundary represented the results that could be obtained under the best conditions, and whose breadth (it was very broad) represented the depth of our ignorance as to what were the best conditions and how they could be obtained. At that time there was no Orsat or Hempel gas apparatus or CO_2 indicator, and no one knew what composition of gas was coincident with the best efficiency. The field of ignorance is now narrowed, so that with analysis of the gas and of the fuel, with mechanical stokers, and with provision against loss by radiation, air-leakage and short-circuiting, the probable performance of a boiler, under known conditions of air-supply and rate of driving, may be predicted within a margin of error of not over five per cent.

Highest Efficiency with Anthracite.—Taking the heating value of the coal used in the Centennial tests at 14,900 B.T.U. per lb. of combustible, the six boilers giving the highest results show the following:

Name of Boiler.	Rate of Driving, W/S.	Evaporation per lb. Combustible.	Efficiency, Per cent.
Root	2.59	12.094	78.77
Firmenich	1.93	11.988	78.08
Lowe	2.15	11.923	77.65
Smith	2.79	11.906	77.55
Smith	3.74	11.925	77.67
Babcock & Wilcox	2.79	11.822	77.00
Galloway	4.83	11.583	75.44
Galloway	5.41	11.216	73.05

The favorable conditions which led to obtaining these high results were: Selected egg coal, dry and low in ash; expert firing; low temperature of water in the boiler. It is not to be expected that these results can be equaled in modern practice with small sizes of anthracite, except by the use of mechanical stokers and control of the air supply with the aid of gas analyses.

Impossible Boiler Performances. (*Power,* Jan. 17, 1911).—There are being circulated printed records of tests conducted at the plant of the American Printing Company, Fall River, Mass., upon horizontal return-tubular boilers, in which an evaporation of 16.69 lbs. of water from and at 212° is claimed.

Assuming that each pound of combustible makes 20 lbs. of gas and that the gas leaves the boiler 400° above the room temperature, such a performance would call for a coal of over 18,000 B.T.U. per pound of combustible, even allowing nothing for radiation; and no such coal has ever been mined.

At the time that this impossible performance is claimed to have been effected the boilers were fitted with a device known as the Cornell fuel economizer. This consists of a number of metallic retorts behind the bridge wall, into which steam is admitted, and it is claimed that the steam in passing through them is decomposed into its constituent gases, oxygen and hydrogen, and that it is the combustion of the hydrogen which supplies the extra heat necessary to obtain the high evaporation reported.

This claim has been exploded over and over again in *Power.* Even if the steam is so decomposed it takes as much heat to decompose it as the gases produced will generate in combustion. When hydrogen is burned, two atoms of hydrogen unite with one of oxygen to form H_2O or water vapor—steam. The decomposition of steam into hydrogen and oxygen is a reversal of the process, and takes just as much

energy in the form of heat as was produced, or will be produced again, by the reunion of the gases in combustion. (See Heat Absorbed by Decomposition, page 22.)

Test of a Corliss Vertical Tubular Boiler with Anthracite.—In connection with a test of the Pawtucket, R. I., pumping engine in 1889 by Prof. J. E. Denton,* a 72-hour test was made of three Corliss vertical tubular boilers, with stove size anthracite. Each boiler had 48 3-in. tubes, 14 ft. long. The total heating surface in contact with water in the three boilers 1231 sq. ft., and the superheating surface 508 sq. ft. The total grate surface was 45 sq. ft. The test is remarkable in showing high economy, 12.11 lbs. evaporated from and at 212° per lb. combustible, or 76.5% of efficiency, at a very low rate of driving, 1.58 lbs. water evaporated from and at 212° per sq. ft. of heating surface per hour, and 4.9 lbs. coal burned per sq. ft. grate per hour. The analysis of the coal was as follows: Moisture, 1.80; ash, 6.90; C, 79.30; H, 4.60; S, 0.85; O, 4.65; N, 1.90. B.T.U. per lb. combustible, by Dulong's formula, 14,876. During the test the coal showed 3% moisture. The average analysis of the gases was CO_2, 8.7; CO, 0.3; O, 10.8; N, 80.3; corresponding to 20.85 lbs. gas per pound of coal.

Tests of a Rust Water-tube Boiler with Pittsburgh Coal.—The accompanying table gives the principal results of two tests made by the author in 1906 on a Rust water-tube boiler rated at 335 H.P., provided with a Roney stoker and an extension furnace. One test was made to determine the economy when driven at or near the builders' rating and the other to determine the capacity when driven at the highest rate the chimney draft would permit. The results were the highest on record at that date for coal containing over 30 per cent of volatile matter in the combustible, and they have been exceeded since with similar coal only with boilers provided with exceedingly large combustion chambers and when the rate of feeding coal and the force of draft were controlled in accordance with the indications of chemical analyses of the flue gases. The following notes are taken from the author's report of these tests.

The results, high as they are, can undoubtedly be duplicated at any time when the same conditions under which these tests were made can be obtained, viz., uniform rate of driving, without having to shut off the draft at any time during the day to lower the steam pressure, and without having to force the fires to raise the pressure; the boiler clean inside and out; a fire-brick furnace and an automatic

* Tenth Annual Report of the Water Commissioners, City of Pawtucket, R. I., 1890.

stoker; the brickwork free from leaks of air; the draft and rate of feeding the coal adjusted to each other so as to burn the coal without smoke and without any greater excess or air than is necessary for complete combustion; and practically no loss of coal through the grate bars.

TESTS OF THE RUST WATER-TUBE BOILER, 1906.

		Capacity Test.	Economy Test.
Duration of trial	Hours	8	10
Weight of coal as fired	Lbs.	21,310	11,850
Moisture in coal	Per cent	3.00	2.47
Ash and refuse in dry coal	Per cent	13.29	14.01
Equivalent water evaporated from and at 212° into dry steam	Lbs.	194,643	121,511
Dry coal per sq. ft. of grate surface per hour	Lbs.	38.00	17.01
Evaporation from and at 212°:			
per sq. ft. heating surface per hour	Lbs.	7.26	3.63
per lb. coal as fired	Lbs.	9.134	10.254
per lb. dry coal	Lbs.	9.416	10.505
per lb. combustible	Lbs.	10.859	12.216
Horse-power developed	B.T.U.	705.2	352.2
Per cent of builder's rated power developed	H.P.	210.5	105.1
Calorific value of the dry coal per lb.	B.T.U.	13,202	13,428
Calorific value of the combustible per lb.	B.T.U.	15,161	15,554
Efficiency of the boiler (based on combustible)	Per cent	69.17	75.85
Efficiency of the boiler, furnace and grate (based on dry coal)	Per cent	68.88	75.55
Force of draft at base of stack	Av'ge in.	1.05	1.1
" " between damper and boiler	" "	0.72	0.32
" " over fire	" "	0.34	0.17
Range of draft pressures, flue	Ins.	0.65 to 0.78	0.25 to 0.37
" " " furnace	"	0.24 to 0.41	0.08 to 0.23
" " " differences	"	0.30 to 0.48	0.10 to 0.18
Moisture in steam	Per cent	0.83	0.70
Temperature of gases escaping from boiler	Deg. F.	718	503
Temperature of feed water	Deg. F.	42	42
Steam pressure, by gage	Lbs. per sq. in.	137	132
Grate surface, 68 sq.ft., Roney stoker. Heating surface 3350 sq. ft.			

Each test was started with the hopper full of coal and the boiler in running condition, the fires having been thoroughly cleaned an hour previously. The test was stopped in the same condition. The coal was of the quality regularly used in the works. It may be classed as crushed run-of-mine, and contained lumps of all sizes from 3-in. cube down to fine slack. The quality differed on the two days, according to the chemical analysis. The draft was regulated by a damper in the flue leading to the stack, it being kept wide open during the capacity test, and fixed at less than half opening during the economy test. The draft in the stack remained nearly constant.

A study of the conditions of draft in the furnace and flue as

shown by an Ellison or other multiplying draft gage may be of considerable service in leading to improving both the capacity and the economy of a boiler plant. The draft in the stack, the atmospheric pressure under the grates, and the resistance to the passage of gas through the boiler structure are all nearly constant for a given boiler. The principal variable condition is the resistance offered by the coal on the grate, and this condition is indicated by the reading of the two draft gages, one at the furnace and the other at the flue between the boiler and the damper. When the difference between the readings of the two gages is smaller than normal it indicates that a small quantity of gas is passing through the boiler structure, which may be due to a choked grate, and this indication is confirmed if the draft in the furnace is higher than normal. If the difference is greater than normal and the draft in the furnace is light, there is too thin a bed of coal on the grate, or on part of it, and an excessive quantity of air is passing into the furnace.

Tests of a 640 H.P. B. & W. Boiler with a Taylor Stoker.—From the results of a series of 19 tests made at the Waterside station of the N. Y. Edison Co., in 1907, the following figures for 13 tests with semi-bituminous coal are selected:

W/S..lbs.	3.55	3.74	4.12	4.45	4.52	4.61	4.61	4.65	4.79	4.82	4.99	6.30	6.51
E......%	73.1	74.2	79.3	80.7	80.9	78.7	75.8	80.7	75.1	80.7	77.6	76.6	74.5
E_1, by formula...	81.4	81.0	80.3	79.6	79.5	79.3	79.3	79.2	78.9	78.9	78.5	75.9	75.5
Diff. E_1-E	−8.3	−6.8	−1.0	+1.1	+1.4	−0.6	−3.5	+1.5	−3.8	+1.8	−0.9	+0.7	−1.0
Radiation, etc, % .	14.6	14.6	10.0	6.8	7.7	9.1	13.0	8.3	13.6	7.7	13.0	12.5	15.1

The formula with which the boiler efficiency E is compared is $E = 82.5 - 2(W/S - 3)$. It is abtained by plotting the efficiencies obtained at rates of evaporation in excess of 4 lbs. per sq. ft. of heating surface per hour. The results are somewhat erratic, and the variation in composition of the flue gases (CO_2 10.9 to 16.5, O, 1.3 to 7.9) is not sufficient to account for them. It is noticeable that all the results that show efficiencies lower than those calculated from the formula also show high losses due to radiation and unaccounted for. The actual loss by radiation was probably not much in excess of 1%. The unaccounted for loss may be largely due to incomplete combustion of CH_4 distilled from the coal and of H from the decomposition of moisture in the coal, which was rather high (2.2 to 4.0%) for semi-bituminous. The great fluctuations in the unaccounted for loss under conditions that were uniform so far as could be ascertained indicate errors in the coal measurement, due to the fact that the tests were not over 8 hours long, and the difference in quantity and condition of the coal on the grates at the beginning and end of a test might be considerable. The furnace conditions were not the most favorable for high economy at rapid rates of driving, for the stoker was installed in the old setting of the boiler which had only a moderate sized combustion space. The

temperature of the chimney gases was low in all the tests, ranging from 418° F. for $W/S = 3.55$ to 519 for $W/S = 6.51$. At the date named (1907) the efficiencies were the highest that had ever been obtained at rates of driving in excess of 4 lbs. from and at 212° per sq. ft. of heating surface per hour. Of the other six tests of the series, five were made with bituminous coal, averaging 27.4% volatile matter in the combustible, and much lower efficiencies were obtained, as below:

W/S........	3.78	3.98	4.80	4.88	5.32
E.........	71.5	74.4	69.4	76.4	73.9

One test was made with coke at a low rate of driving, giving $W/S = 3.98$, $E = 73.6\%$.

Tests with Taylor Stokers.—The following condensed summary is abstracted from the reports of numerous tests published by the American Engineering Co., makers of the Taylor stoker:

No.	Kind of Boiler.	Per cent of Rating.	$\frac{W}{S}$	Efficiency of Boiler and Furnace.	Gas Analysis.			Temp. of Flue Gases.	Duration of Test, Hours.
					CO_2	O	CO		
1	B. W.	175	6.04	77.6	12.7	6.7	0	449	24
2	"	130	4.50	78.6	11.9	7.5	0	429	24
3	"	249	8.59	71.6	13.4	5.5	0.09	527	4
4	"	244	8.42	72.6	15.5	1.9	0.96	498	4
5	"	190	6.56	74.4	....	...	....	599	12
6	Manning	147	4.89	76.4	10.4	7.8	0	600	5
7	"	151	5.01	71.0	13.3	7.0	0	598	24
8	"	151	5.02	71.8	11.8	7.7	0	599	24
9	"	150	4.97	72.1	12.4	7.3	0	599	39
10	B. & W.	180	6.15	76.8	12.7	...	....	544	8
11	"	117	4.12	78.5	13.3	5.9	0	455	8
12	"	127	4.45	79.6	12.2	7.5	0	473	8
13	"	129	4.52	79.8	13.0	6.2	0	468	8
14	"	131	4.61	77.1	12.7	6.5	0	468	8
15	"	131	4.61	75.3	13.5	5.8	0	473	8
16	"	137	4.82	77.6	13.5	4.7	0	492	8
17	"	142	4.99	76.5	16.2	1.4	0	475	8
18	"	185	6.51	72.7	16.5	1.3	....	519	3.85
19	Edge Moor	188	6.36	71.3	12.4	5.8	0	546	16
20	Geary	82	2.77	70.2	....	...	....	370	16
21	"	155	5.37	76.8	....	...	....	430	4
22	Stirling	133	4.58	76.1	14.5	...	....	.....	8
23	B. & W.	139	4.80	79.7	13.3	6.4	0.22	577	8
24	Stirling	151	5.22	77.1	14.0	5.5	0.42	575	24
25	"	108	3.72	80.3	13.7	5.8	0.10	493	24
26	"	163	5.62	77.8	14.7	4.6	0.12	574	50
27	"	93	3.22	77.9	11.9	8.0	0.06	487	48
28	"	211	7.29	75.8	15.4	3.9	0.17	651	26.5
29	"	121	4.18	79.2	13.8	5.7	0.04	535	48
30	"	185	6.40	76.4	14.2	5.1	0.08	647	24
31	(?)	104	3.58	78.5	....	...	....	516	8
32	B. & W.	167	5.78	72.4	....	...	....	553	7
33	Ret.Tubular	136	4.69	77.0	12.5	...	....	430	6
34	Edge Moor	159	5.47	78.2	14.3	3.9	0.24	499	12

NOTES: W/S = lbs. water evaporated from and at 212° per sq. ft. heating surface per hour Kind of coal: Nos. 1 to 22, semi-bituminous, Nos. 23 to 34, bituminous. Location of boilers, 1 to 4, Boston Elevated Railway Co., South Boston; 5, Old Colony Ry. Co., Quincy, Mass., 6 to 9, Everett Mills, Lawrence, Mass.; 10, Narragansett Elec. Lt. Co., Providence, R. I.; 11 to 18, New York Edison Co., Waterside Station; 19, N. Y. Central R. R. Co., Albany, N. Y.; 20, 21, National Museum, Washington, D. C.; 22, Wardlaw-Thomas Paper Co., Middletown, O.; 23, Cleveland, O., Ry. Co.; 23 to 30, Detroit Edison Co.; 31, Public Lighting Co., Detroit, 32, Commonwealth Edison Co., Chicago; 33, Fox River Paper Co., Appleton, Wis.; 34; Milwaukee El. Ry. & Light Co.

In the Manning boiler tests, Nos. 6 to 9, the heat balance shows the "radiation and unaccounted for" loss in the four tests to be 7.8, 14.3, 12.8 and 13.2 per cent. Mr. Chas. H. Manning, who reports the tests, says of No. 6, "the results give an exaggerated efficiency" due to an error in the coal measurements. It is not to be expected that a 5-hour test will give results that are even approximately accurate, but "the radiation and unaccounted for" losses in the other three tests are unusual for semi-bituminous coal. The low efficiency in these tests is accounted for by the facts that the tubes were much clogged with soot, a reason for the high temperature of the waste gases, and that the plant was run by men of short experience with the stokers.

Another series of tests with the Taylor stoker is reported by Horace Judd in *Power,* June 23, 1914. The first six were made on a Babcock & Wilcox cross-drum boiler of 2485 sq. ft. of heating surface and the other four on a Flannery cross-drum water-tube boiler of 3130 sq. ft. of heating surface. Coals of rather low grade were used, the heating value per pound of combustible ranging from 14,191 to 14,980 B.T.U. The results were in general considerably lower than those given in the above table, which may be accounted for by the smaller size of boilers, which would make the percentage of radiation loss greater, the lower grade of coal, and the higher percentage of moisture in the coal (2.73 to 11.62 per cent). The tests were only of 10 hours duration each, which might cause an error of 3 or 4 per cent in the recorded results, on account of the possible variation in quantity and quality of the partially burned coal in the furnace at the beginning and end of the tests. The most important results are the following:

No. of test	1	2	3	4	5	6	7	8	9	10
Rate of driving, W/S	5.90	5.84	5.12	5.68	6.02	5.76	4.33	5.76	6.38	7.00
Efficiency, boiler and furnace	71.8	77.3	74.7	69.4	69.3	66.7	71.0	...	66.0	68.1
Efficiency, b., f., and grate	69.9	72.5	69.9	67.1	66.3	63.5	67.6	65.8	59.0	
Radiation, etc.	7.19	1.25	5.65	8.39	9.75	12.93	12.17	12.48	15.82	11.41

The great fluctuation in the loss by radiation and unaccounted for, from the impossibly low figure 1.25 to the very high figure 15.82, is evidence of large errors in the coal record of these tests.

Mr. Judd says in his report of these tests: The chief controlling factors influencing the efficiency of a Taylor stoker at overload capacity appear to be:

1. Size of the unit.
2. Percentage of overload.
3. Character of coal.
4. The use of indicating boiler room appliances.
5. The intelligence of the fireman.

The factor of most importance is, without doubt, the degree of intelligence which the fireman possesses and the interest he takes in improving the operating conditions.

Test of an Edge Moor Water-tube Boiler.—Three tests of an Edge Moor water-tube boiler with a Taylor stoker and Foster super-

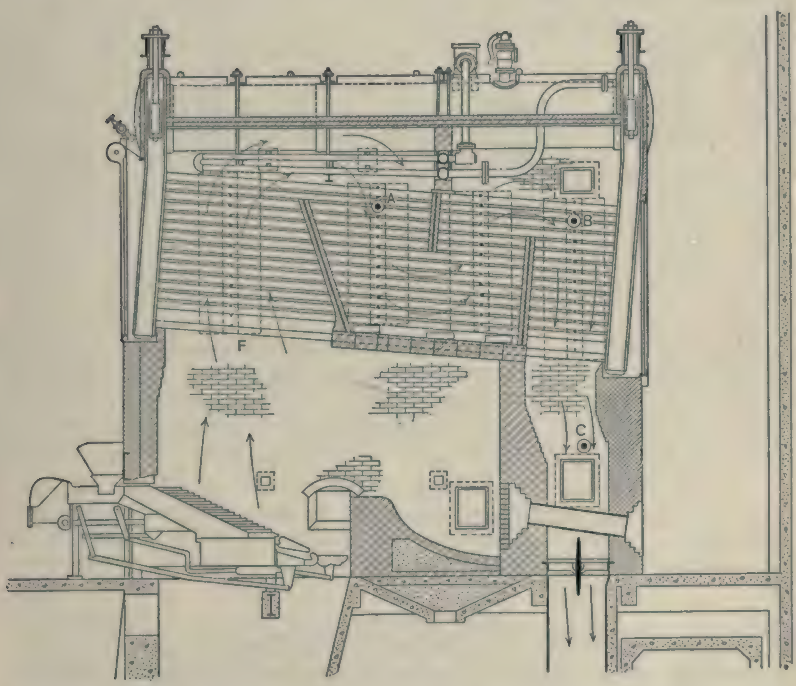

FIG. 270.—EDGE MOOR BOILER WITH TAYLOR STOKER AND FOSTER SUPERHEATER.

heater were made at the Westport station of the Consolidated Gas, Electric Light and Power Co., of Baltimore in 1913. A sectional view of the boiler and setting is shown in Fig. 270. The coal tests are given below. The first two tests were each 8 hours long; the third 2 hours, no coal record being made.

Per cent of rating developed	210.5	248.5	318
Steam pressure, pounds per square inch gage	169.7	167.4	172.1
Superheat, deg. Fah	130.4	106.6	103.5
Pressure in tuyere box, ins. of water	2.69	3.68	5.3
Draft in furnace, ins. of water	.09	.03	......
Draft at bottom of last pass, ins. of water	.76	.88	1.2
Coal as fired, per hour	5031	6000	
Coal per square foo grate per hour (total grate surface 120 sq. ft.)	42	50	
Temperature of escaping gases, deg. Fahr	550.6	584.7	
Average interval between dumpings, hours	2.6	2.0	
Equivalent evaporation per pound of dry coal, lbs.	10.98	10.77	
Equivalent evaporation per square foot of water-heating surface per hour, pounds	7.26	8.57	10.97
Horsepower developed (rated H.P., 736)	1549	1829	2340
Efficiency of boiler and grate, per cent	74.7	72.8	
Moisture in coal	3.27	2.39	
Volatile matter	19.73	18.62	
Ash	9.43	8.74	
Sulphur, separately determined	1.93	1.63	
B.T.U. per pound coal	13,797	14,018	
" " " combustible	15,804	15,683	
Gas analyses—above damper:			
CO_2	15.6	16.1	
O	3.4	2.6	
CO	0.03	0.16	
Appearance of smoke	Haze	Light gray	

Value of the Rear Passes.—Referring to the cut, Figs. *A*, *B*, and *C* show the positions where the thermo-couples of an electric pyrometer were placed. The couples were moved in and out until a position was found where the temperature indicated was highest. The average of several readings obtained in the two 8-hour tests were as follows:

	At about 210% of Rating.					At about 248% of Rating.				
	At *A*		At *B*		At *C*	At *A*		At *B*		At *C*
	918°		618°		560°	1005°		684°		609°
Diff.		300		58			321°		75°	

The report of the test contains the following:

With high percentage CO_2 and good coal, the rise in efficiency or the percentage of the calorific value of the coal absorbed, per 100 degrees drop of gas temperature is about 2.75 per cent. On this basis the gain in efficiency due to the last pass or from *B* to *C* is a little more than 1.6% at 210% of rating, and 2.1% at 248% of rating. The percentages of the total heating surface (including superheater) in the different sections of the boiler are, approximately, from the fire to *A*, 45%; from *A* to *B*, 40%; from *B* to *C*, 15%. The percentage of the calorific value of the coal absorbed in the different sections is, approximately as follows:

Sections.	*F* to *A*.	*A* to *B*.	*B* to *C*.	Total.
Per cent of heating surface......	45	40	15	100
Absorbed at 210% of rating....	64.9	8.2	1.6	74.7
" " 248% of rating....	61.9	8.8	2.1	72.8
PER CENT OF THE TOTAL HEAT ABSORBED.				
At 210% of rating.............	86.9	11.0	2.1	100
At 248% of rating.............	85.0	12.1	2.9	100

Let it be supposed that in the test at 248% of rating the gases were allowed to escape at *A*. Only 45% of the total heating surface would then have been in use, while 85% of the total steam would have been generated. This would give an equivalent evaporation per hour of 15.3 lbs. per square foot of heating surface, and a percentage of rated capacity, based on 10 sq. ft. of surface per horsepower, equal to 443%. The efficiency would then have been 61.9% and the gases would then have escaped at 1005°.

Considering the decreasing efficiency of the heating surface as the temperature drops, a boiler may be logically divided into two sections—the capacity section, which includes the hotter surface, and the economizer section, which includes the colder surface. The question has sometimes been raised if it really pays to put in this economizer section.

An analysis of the fixed and maintenance charges on this part of the boiler will show that for land service the investment is nearly always a very profitable one. This is because the first cost is comparatively small, while the maintenance is negligible. The heating surface being practically all tube surface (the fronts, headers, etc., being the same whether the tubes are long or short), is therefore inexpensive, while the costs of the additional size of building, the extra brickwork and slight extra height of chimney required do not amount to a great deal. The determining factor may be the extra real estate; but seldom will it occur that the saving in fuel due to the extra efficiency gained will not show a most desirable net profit.

Time Required to Obtain a High Rate of Evaporation from a Banked Fire.—The Edge Moor boiler referred to above was kept idle with a smouldering banked fire for an entire week, coal being fed at the rate of about 220 lbs. per hour. At the end of the week the fuel bed was in poor condition and the brickwork was cold. Fresh coal was then fired and forced draft applied. The steam meter records were plotted every half minute, and they showed that the times required for the boiler to furnish steam at different percentages of the boiler's rating were as follows:

Per cent of rating..................	50	100	150	200
Time in minutes....................	1.7	2.3	4.7	7.8

Recent Experience with the Delray (Detroit) Boilers. (J. W. Parker, Jour. A. S. M. E., 1913.)—Since the first performance tests, in 1911, six more of the same type and size (Stirling W type, 2365 H.P. each) have been installed, the last two in the autumn of 1913. From Oct. 15, 1912, to Nov. 1, 1913, there have been but two tubes replaced in seven boilers whose average age is two years. Taking all stoppages in consideration, including those for repairs of brick-work and of stokers, the boilers were ready for service 95% of the time; 98% of the five full load days of the week, and 100% of the peak load periods.

The Detroit Edison Company is now building a power plant to contain six 20,000 KW. turbines served by 12 2365 H.P. boilers, which is two boilers to one turbine, with no spares, or 10,000 KW. per boiler. At normal full load on a given turbine unit, the two boilers will operate at approximately 191% of the builder's rating based on 10 sq. ft. of heating surface per boiler horse-power. If, with six boilers running at this rating, one boiler should go completely out of commission, the other five would have to carry the entire load of 60,000 KW and thus operate at 235% of rating, which is perfectly possible. The settings and auxiliaries are being designed to allow of continuous operation at 255% of rating, which would enable three boilers to take the full load of four, i. e. 40,000 KW. Recently, one of the Delray boilers was isolated from the rest of the plant with a 15,000 KW., seven-stage Curtis vertical turbine, and over 11,000 KW. was carried for an hour without difficulty.

Method of Operating the Delray Boilers.—It is economical to run as many boilers as possible at about 90% of rating when the plant load is light, and then carry the peak of the load by increasing the rating on the boilers. In this way, from morning till night there need be no fires banked or broken out of bank, and the firemen can bend their energies instead to manipulating their fires to the best advantage.

This flexibility is at no time more convenient than in summer when provision must be made for a sudden peak load due to a thunderstorm. At Delray, in the summer of 1914 the average day load will be about 63,000 KW., while provision must be made for a storm load of about 82,000 KW., a 30 per cent increase. Boilers ordinarily running at 100 per cent or 125 per cent of rating (a very economical point) will take a 30 per cent increase in load with very little effort. No banked fires will be carried during the daytime.

One fireman fires two units. The control of each unit is brought directly under his hand in every way possible, so that a minimum of time will be wasted in mechanical manipulation. A water tender stationed on a gallery at the top drum level feeds the boiler, but the fireman does everything else in the way of operating. The plan is for one man to operate two stokers, and in addition, to have a head fireman in charge of from six to eight units, whose duty it is to oversee all the fires, and go to the assistance of any fireman who needs

help. On the gage board are mounted steam gages showing pressure at the superheater inlet and superheater outlet and draft gages showing air pressure under the fire, draft at the damper, and draft at the top of the combustion chamber. There is also on this board the record dial of a CO_2 meter. Four samples of gas are drawn from one furnace, automatically mixed, and the resulting analysis is recorded where the fireman can watch it.

Fireroom Personnel. The whole idea is to employ the most expert firemen it is possible to develop, and give each man control of the burning of a very large amount of coal. It is economical to employ a fine type of man and pay him an expert's pay. The present first-class fireman's pay is 40 cents an hour and he is well treated as to vacation and sick leave. A force of firemen is being built up that can obtain remarkable results with their fires. They are acquiring an intelligent understanding of the combustion of coal. At the same time the unit cost of firing is unusually low. The following table is a schedule of the labor necessary to handle 12 boilers of a six-turbine plant with no economizers installed:

LABOR COST OF FIRING A TWELVE BOILER PLANT.

Maximum load		120,000 kw. 12 boilers at	191%
Minimum load		20,000 kw. 4 boilers at	96%
Monthly load factor (November)			46%
Operators employed:			20
Morning shift	6.30– 2.30	2 head firemen at 45 cents	$7.20
		6 firemen at 40 cents	19.60
		2 watertenders at 35 cents	5.20
Afternoon shift	2.30–10.30	2 head firemen	7.20
		6 firemen	19.60
		2 watertenders	5.20
Night shift	10.30– 6.30	6 firemen	19.80
		1 watertender	2.00
			$86.00
Boiler room foremen			15.00
Total cost per day			$101.76

As to furnace conditions, the firemen judge by the CO_2 recorder, by the amount of air pressure necessary for any given boiler load, and by no means least of all by the color of the gases as they tumble over the first baffle and enter the top of the superheater pass. Observation of the furnace gases, as they enter the superheater pass from the top of the combustion chamber, shows that the combustion of volatile gases is entirely complete and that the operation is consequently smokeless. At the same time, the CO_2 charts show remarkably good results, 15% of CO_2 being very common, the average being about 13.5 to 14%. Repeated analyses made with an Orsat apparatus check these recording machines and at the same time discover no more than from a trace to 0.2% of carbon monoxide.

Limitations of Boilers as at Present Installed—Furnace Height. As at present installed, these boilers present certain limitations to being driven at any considerably higher per cent of rating than that already obtained. First, in burning West Virginia long-flaming bituminous coal, it is probable that at, say, 275% of rating and perhaps somewhat lower than that, the flames will reach the top of the combustion chamber, which is 28 feet high. As soon as uncombined combustible gases get over into the superheater pass, the over-all efficiency of the unit will drop, for although secondary combustion will take place, nevertheless some unburned volatile matter must escape.* Smoking will begin immediately after the secondary combustion becomes very considerable. Another limitation is the drop in pressure through the superheater, the automatic check valves and stop valve of the boiler. At 210 per cent of rating on one boiler, the drop in pressure through the superheater is 21 lb. which includes the pressure drop through the automatic check valves, but not that through the main stop valve. At 255 per cent of rating it would be considerably more.

The experience at Delray with very high steam velocities has proved that in mains designed especially for high velocities, such practice is very good, the difficulties being more than compensated for by the reliability, reduced cost and ease of maintenance of the smaller diameters of mains and fittings.

Effect on Tubes.—As for the effect on the front tubes of the type-W boiler, of running at very high rates of evaporation it has been found that the tubes have shown no evidence of injury due to the hard driving. One thing is certain, however, and that is these tubes must be kept clean. Scale which ordinarily would give no trouble, has possibilities for mischief under the conditions of harder driving.

The general conclusions arrived at from the experience had in operating these boilers, is that large units present possibilities of economy of operation and simplicity of power plant design, which are greatly in advance of present steam generating practice.

Tests of Riley Underfeed Stokers.—On page 641 are the principal results of three 8-hour tests of a 625 H.P. Babcock & Wilcox boiler provided with an 8-retort Riley self-dumping underfeed stoker, at the Yonkers power plant of the N. Y. Central & Hudson River R. R., December, 1913.

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* It is probable that the flame could be shortened by the admission of a little more air, either through the stoker or just above the bed of coal. If jets of hot air, at high velocity, so that they would travel clear across the furnace, were blown on or over the fire bed, a much shorter flame would result. The cause of long flame is imperfect mixture of combustible gases with the air required to burn them. Anything that will facilitate the mixture will shorten the flame. The excess air supply might reduce the efficiency to some extent, but this could be tolerated in times of emergency overloads.—W. K.

Rating developed	Per cent	103.2	156.	203.2
Blast under grates	Ins.	1.6	2.69	3.52
Draft over fire	"	0.11	0.11	0.08
Uptake temp.	F	401.	466.6	490.
Superheat	F	93.5	122.2	141.4
B.T.U. dry coal		13,963	14,209	14,320
" combustible		15,705	15,408	15,624
Volatile matter, per cent of combustible	Per cent	26.8	26.4	26.0
Moisture in coal	"	2.5	5.5	2.50
Ash in dry coal	"	11.09	7.79	8.99
Sulphur in dry coal	"	2.58	1.19	1.89
Combustible in refuse	"	16.22	20.65	23.23
Water evap. per sq.ft. H.S. per hour	Lbs.	3.56	5.38	7.01
Effy. boiler and grate	Per cent	77.40	77.30	76.80
Uptake gas analysis: Carbon dioxide	"	10.7	12.0	10.9
Oxygen	"	7.65	6.02	7.44
Carbon monoxide	"	0.03	0.02	0.02

The formula for maximum results, $E = 81 - 1.3(W/S - 3)$. gives for the

rates of driving in these tests, $E =$	80.3	77.9	75.8
The results obtained were	77.4	77.3	76.8
Difference	−2.9	−0.6	+1.0

High Rates of Driving in Steam Fire-engine Boilers. (*Eng. News,* March 28, 1895).—Tests of eleven engines in Boston gave the following results:

Coal per square foot of grate per hour, lbs.	91.1 to 208.0
Water per sq.ft. of heating surface per hour, lbs.	11.13 to 28.57
Water evap. from and at 212° per lb. coal	2.26 to 5.87
Heating surface, square feet	74.0 to 229
Water evaporated per hour, pounds	1630 to 3524

Eight out of the eleven engines gave an evaporation of more than 20 lbs. per sq. ft. of heating surface per hour.

Variation in Gas Analyses.—The accompanying cuts, from an article by A. Bement, in *Power,* Mar. 25, 1913, show the different shapes of CO_2 diagrams that may be obtained under different firing conditions. No. 1 shows a decrease of CO_2 from 7 to 4% in seven minutes with a dirty fire, then a rise to 13%, after the fire was cleaned. No. 2 shows the fluctuations that are common with hand firing. No. 3 shows low CO_2 due to holes in the fire bed followed by high CO_2 after the fire was leveled to close the holes, decreasing as the fire burned thin. No. 4 shows the results obtained from two different firemen. No. 5 shows two kinds of diagrams obtained with a Hawley down-draft furnace with different methods of manipulation. In *B,*

the CO_2 rises after every poking of the fire on the upper grate to cause a part of the coal to fall on the lower grate. When the coal on the lower grate burns away the air supply increases and CO_2 lowers.

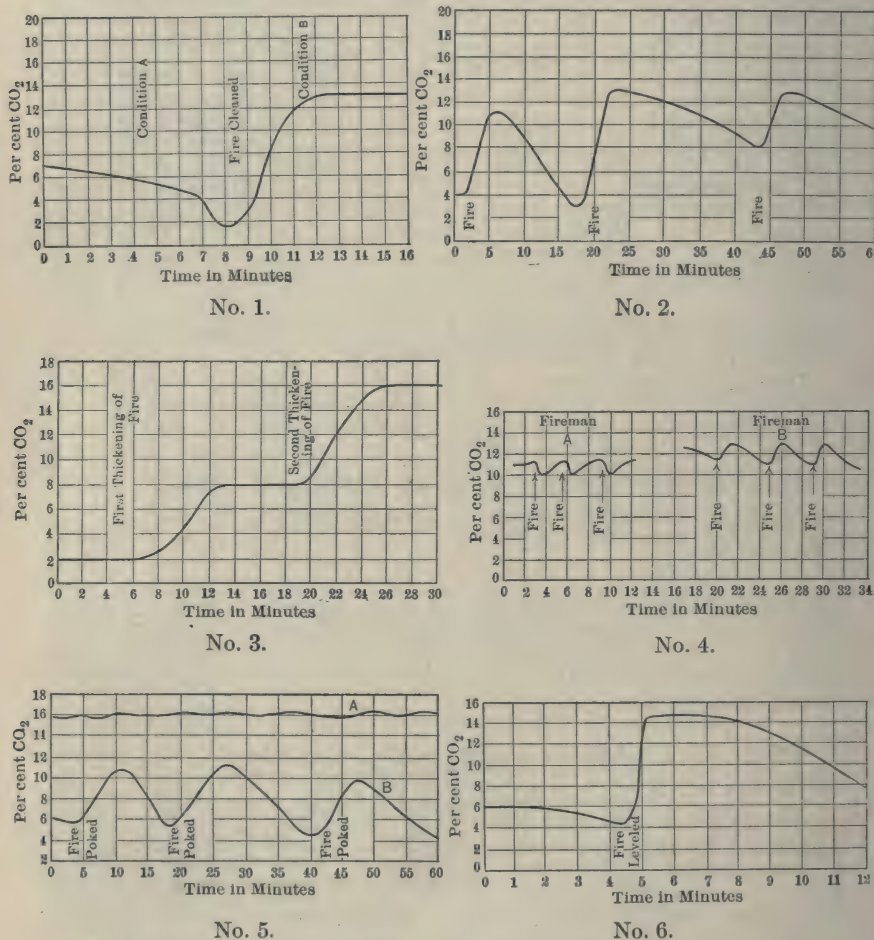
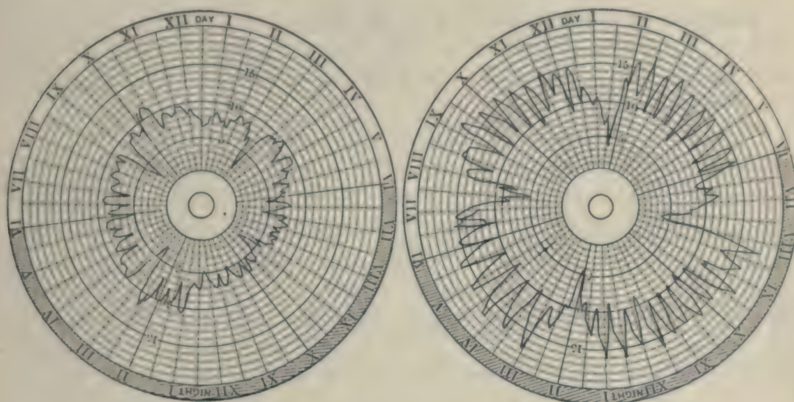


FIG. 271.—VARIATIONS IN CO_2 WITH DIFFERENT FIRING CONDITIONS.

In *A*, the CO_2 is kept at the unusually high level of 16 (rather too high to be true, indicates an error in the apparatus) by frequent poking of the coal to insure always a sufficiently thick bed on the lower grate. No. 6 is another Hawley furnace diagram showing the great improvement due to thickening of the bed of lump coal on the upper grate.

Fig. 272 shows two days' records of a CO_2 meter. The first, with an excessive air supply, shows an average of about 8% CO_2, the second about 12.5%.

Extreme Fluctuations of Gas Analysis with Heavy Firing. (*Eng. Record,* Dec. 23, 1905).—Tests were made to show the com-



Poor firing, air supply in excess. **Good firing.**

FIG. 272.—RECORDS OF A CO_2 METER.

position of the gas from a hand-fired water-tube boiler when the coal (semi-bituminous coking) was fired in large quantities at intervals of about 30 minutes. The results are given in the following table:

No. of Test.	Shovels of Coal Fired.	Minutes after Firing.	CO_2.	O.	CO.	Sum.	Loss of Heat Due to CO, %.
1	20	1	12.4	4.4	1.1	17.9	5.67
2		28	10.7	9.3	0.1	20.1	0.54
3	32	2	14.0	2.1	2.0	18.1	8.09
4		26	16.9	1.2	1.3	19.4	5.00
5	20	2	13.7	2.2	2.5	18.4	10.08
6		23	13.0	6.4	0.0	19.4	0
7	20	2	14.0	2.7	1.7	18.4	7.52
8		17	11.6	8.0	0.0	19.6	0

The fire was barred before test No. 2; leveled to fill holes and low spots 1 minute before test No. 4; barred, but not leveled, 5 minutes before No. 6; barred but not leveled 6 minutes before No. 8. These tests show that CO_2 is not as good a criterion of furnace conditions as O is; for CO_2 13 to 14 is coincident with CO ranging all the way from 0 to 2.5, the first being a nearly ideal and the second an

exceedingly bad condition, and 16.9 CO_2 is coincident with 1.3 CO, also a bad condition. With O 6.4 the conditions are almost ideal, CO_2 13.0, CO, O, but with O 8 or above, CO_2 is always low, the high O and the low CO_2 both indicating excessive air supply. The figures in the last column represent the loss of heat due to burning C to CO instead of CO_2, calculated by the formula. Loss, $\% = 69.5\frac{CO}{CO+CO_2}$.*

Relation of CO_2, O, and CO in 94 Tests.—The following table is made from figures selected from tables given by E. A. Uehling in Jour. A. S. M. E., Nov., 1910. All the analyses showing 14 CO_2 or upward are given.

Oxygen, Per cent.

	1–1.5	1.6–2	2.1–2.5	2.6–3	3.1–3.5	3.6–4	4.1–4.5	4.6–5	5.1–5.5	5.5–6
CO_2.			Carbon Monoxide.							
14.0			1.1				0.2		0	0
14.1								0	0	0
14.2				0.7					0	
14.3			0.8						0	
14.4				0.5	0.5		0.2		0	
							0.1		0	
14.5		0.7					0.1		0	
		1.0							0	
14.6		1.0	0.9	0.5						
		0.8								
14.7		0.9		0.7		0.1				
		0.6								
		0.9								
14.8	1.1			0.5	0.3		0			
							0			
15.0	0.8	0.9	0.6	0.3	0.2	0	0			
	0.8	0.5	0.5		0.2					
		0.6	0.8							
			0.5							
15.1			0.5				0	0		
			0.5							
15.2			0.5			0				
			0.4							
15.3		0.6	0.4				0			
		0.5								
15.4			0.5	0.3	0					
15.5	0.8			0.2		0	0			
						0				
						0				
15.6	0.5	0.4	0.5	0.3						
15.7		0.3	0.3							
15.8	0.5			0		0.6				
15.9					0					
16.0	0.8				0					
	0.4				0					
16.1					0					
16.2		0.2								
16.3					0	0				
16.4	0.3	0.2								
16.5	0.4	0.2		0						
16.6			0							
Av.	0.64	0.61	0.55	0.36	0.12	0.09	0.06	0	0	0

* The formula is derived as follows: Since the same volume of gas is formed by burning 1 lb. C to CO as by burning it to CO_2, the fraction of the volumes, $CO \div CO+CO_2$ equals the fraction of 1 lb. that is burned to CO. As 1 lb. of C burned to CO_2 generates 14,600 B.T.U., but only 4450 B.T.U. when burned to CO, the difference, or loss, of 10,150 B.T.U. is 69.5% of 14,600.

RELATION OF CO TO CO_2.

No. of Tests.	CO_2.	CO.	Av. CO.
36	14 to 14.8	0 to 1.1	0.37
34	15 to 15.5	0 to 0.9	0.33
13	15.6 to 16	0 to 0.8	0.33
10	16.1 to 16.6	0 to 0.4	0.13

RELATION OF CO TO O.

No. of Tests.	O.	Av. CO_2.	Av. CO.	Heat Loss Due CO.
54	1 to 3	15.2	0.55	2.47%
40	3 to 6	14.9	0.006	0.03%

This shows that O is a more reliable index of furnace conditions than CO_2. With CO_2 from 14 to 16 CO may be anywhere between 0 and 1.1%, while with O between 3 and 6 there are only two tests out of 40 in which CO exceeded 0.3%. With O above 4 only 2 tests out of 22 had CO as high as 0.2%.

Air Leaks through Boiler Settings. A. A. Cary, *Iron Age*, Oct. 10, 1912.—Analyses of the gases in the furnace and in the flue of two horizontal tubular boilers and one water-tube boiler showed the following results:

	No. 1.	No. 2.	No. 3.
Excess air in the furnace, per cent.......	70	49	45
Excess air in the flue..................	103	71	96
Temperature of flue gases, degrees F.....	543	482	..
Calculated temperature if there had been no air leakage between furnace and flue	607	561	..

The analyses of the gases in No. 3 water-tube boiler showed, furnace CO_2, 12.71; O, 6.62; flue, CO_2, 9.05; O, 10.42. These analyses were made under natural draft conditions. With forced draft no inward air leakage was found, but on the contrary a slight outward leakage of gas.

Tests of Washed Grades of Illinois Coal.—A report of an extensive series of 58 boiler trials with washed coal and six trials with unwashed coal, by C. S. McGovney, is printed in Bulletin No. 45 of the University of Illinois Engineering Experiment Station, 1909. A 210 H.P. Heine boiler with a Green traveling chain grate was used for the tests. The fire brick furnace extended 4 ft. in front of the inside of the front of the boiler setting, and the combustion chamber was roofed over with fire brick supported by the lower row of boiler tubes for a distance of 13 ft. from the front wall. The conditions were thus favorable for complete combustion of the volatile matter of the coal and the suppression of smoke. The figures in the following table are selected from the records of the tests of washed coal in which especial care was taken to keep the furnace conditions uniformly good by regulating the thickness of the fire, and leveling it frequently so as to avoid the formation of air holes. Where two

figures appear separated by a hyphen they represent the extreme range of results obtained in a series of from four to eight tests. The other figures are averages. The coal, from three washers in Vermillion and Williamson counties, was of fairly uniform quality, ranging from 14,035 to 14,416 B.T.U. per pound of combustible, and the principal difference was in the size of the several grades, as shown in the table.

Reference No.	1	2	3	4	5
Size of coal, in.	1¾ to 1	1 to ¾	⅞ to ⅜	⅜ to 0	¼ to 0
Moisture, %	8.06–11.43	8.90–10.12	16.48–22.63	21.25–21.72	13.94–21.49
Ash in dry coal, %	11.07–12.80	9.70–12.66	8.88–14.75	14.40–16.15	10.03–15.69
B.T.U. per lb. combustible	14,416	14,395	14,121	14,035	14,135
Volatile matter, % of comb.	38.61	37.54	43.90	44.46	37.59
Lbs. comb. per sq.ft. grate per hr.	17.9–20.1	15.9–30.10	12.33–25.79	16.81–21.70	13.27–17.28
H.P. per sq.ft. of grate	5.36–5.95	4.83–8.42	3.84–7.73	4.29–5.51	3.02–4.59
H.P. per cent of rating	97.4–108.2	88–153	69.9–140.5	78–100.2	55–83.6
Water evap. from and at 212° per sq.ft. H.S. per hr.	3.48–3.86	3.60–5.47	3.11–5.02	2.79–3.58	1.96–2.98
Efficiency of boiler	66.1–68.2	65.5–71.5	70.1–72.9	59.7–61.0	52.8–60.7
Efficiency including grate	64.1–65.4	64.2–70.5	69.2–71.6	55.9–57.3	48.9–58.6
CO_2 in flue gas, %	9.6–12.4	10.27–11.48	10.93–12.55	6.16–6.90	4.6–6.2
Excess air flue gas, % avge.	81.8	51.8	54.3	135.9	169.5
Lbs. air per lb. comb. avge.	21.05	17.93	17.30	28.05	31.56
Temp. of flue gases ° F.	608–648	565–748	489–667	581–624	556–607
Draft required to develop rated H.P., in. of water	0.32	0.23	0.24	0.89	0.83*

* Only 83.6% of rating was developed with this draft.

The highest efficiency in the whole series, 72.95%, was obtained with the ⅞- to ⅜-in. coal when the boiler was driven at 139.6% of rating. The CO_2 in the flue gases was 12.55% and their temperature the lowest in the whole series, 489° F., The moisture in the coal in this test was 19.49%. Eight tests were made with this coal, and the results are all relatively high. Another set of five tests was made with the same coal when no especial precautions were taken to keep the fire in the best condition, and the boiler efficiency was only 62.8-66.8%, and the "over all" efficiency, including boiler and grate 58.2-64.0%. The average "over all" efficiency of the eight tests was 70.1% and of the five tests 61.9%, showing a saving of fuel due to proper control of the fire of $8.2 \div 70.1 = 11.7\%$.

In the tests with the small sizes of coal it was not found possible to control the furnace conditions so as to develop the rated capacity of the boiler without making holes through the fire, causing a great excess of air to pass into the furnace, which retarded the rate of combustion. It is evident that much is yet to be learned in regard to the best method of burning the finest sizes of coal.

It is to be noted that these tests were made under far better conditions than are usually obtainable, and the results are much higher than those obtained in common practice.

Tests with North Dakota Lignite, made by D. T. Randall and Henry Kreisinger, are reported in Bulletin 2 of the Bureau of Mines, 1910. This lignite is difficult to burn in ordinary boiler furnaces,

but the tests have shown the possibility of designing suitable furnaces for burning it profitably. In these tests a Stirling boiler and a furnace consisting of a Dutch oven and an arch with downwardly inclined roof, extending about 5 ft. beyond the grate bars, were used. The lower edge of the fire door was 21 ins. above the level of the rocking grate. The furnace was designed to run on the gas producer principle. Air for the combustion of the gases, preheated in coils from 200° to 300° F. was introduced, at a pressure of 0.5 to 1 in. of water, through numerous small openings in the bridge wall. Additional air was admitted through openings over the fire from an air space in the double roof of the Dutch oven. The air supply under the grates was furnished by Argand steam blowers. With rates of combustion exceeding 25 lbs. of fuel per sq. ft. of grate per hour the flame extended into the space in front of and above the arch. At the close of each test a quantity of clinker amounting to several hundred pounds was found on the grate, not being removed by the operation of rocking the grate bars. The tests were made with running start and stop, a correction for the clinker being made by stopping the tests with the fuel bed 3 or 4 ins. higher than at the start. The error of the weight of the fuel consumed was estimated as possibly 1½% too high or too low. Fifteen tests in all were made, and the two given in the following table represent the extreme range of the rates of combustion:

TESTS WITH NORTH DAKOTA BROWN LIGNITE.

Test No.		4	11
Duration of test	Hrs.	14.75	10.03
Dry fuel per sq. ft. grate per hour	Lbs.	19.52	29.43
Refuse in dry fuel	Per cent	14.08	12.49
Moisture in fuel as fired	"	44.26	42.88
Volatile matter in combustible	"	50.52	49.24
Sulphur in dry fuel	"	1.42	1.68
Water evaporated from and at 212° per hour:			
per lb. fuel as fired	Lbs.	3.36	3.48
per lb. dry fuel	"	6.02	6.10
per lb. combustible	"	7.34	7.48
Horse-power developed, per cent of rating	Per cent	73.9	112.8
Efficiency of boiler and furnace	"	61.2	62.5
" " " including grate	"	57.7	59.2
" over all, deducting steam used by blower	"	52.6	54.5
Temperature of flue gases	Deg. F.	436	570
Gas analysis, CO_2		9.79	10.92
O		9.27	8.26
CO		0.05	0.23
Loss due to imperfect combustion, radiation, and unaccounted for	Per cent	11.78	5.78

NOTES.—The visible smoke during all the tests was very light and appeared to consist mostly of water vapor. Superheated steam was used in the ash pit blowers (Argand). Test No. 11 represented the highest capacity that could be developed with the apparatus without great decrease of efficiency. The boiler was rated at 258 horse-power. Heating surface 2587 sq.ft., grate surface, 54 sq. ft., ratio 46 to 1. It is evident that the capacity might have been much greater if the grate surface had been larger. A curve of the 15

tests shows that the efficiency of boiler and furnace drops from about 63 to 57% as the rate of combustion increases from 19 to 29 lbs. per sq. ft. of grate per hour. This drop is perhaps mostly due to less complete combustion of the gaseous combustible in the combustion space of the boiler.

The results, says the Bulletin, show that this combination of boiler and furnace gives good results with North Dakota lignite. A fuel efficiency (over all) of from 55 to 58% can be obtained with the full capacity of the boiler. The steam blower for the ash pit is inefficient, and there is no gain in supplying superheated steam to it. A considerable saving could probably be made by substituting a fan such as is commonly used for forced draft.

Tests with Coke-oven and Blast-furnace Gas are reported in *Stahl und Eisen,* Aug. 1913, Jour. A. S. M. E., Oct. 1913. A double flue boiler of 925 sq. ft. heating surface, fired with coke-oven gas, and driven at the rate of 2.4 and 2.6 lbs. per sq. ft. heating surface per hour, gave 74.9 and 80.2% as the combined efficiency of boiler, superheater and economizer. A similar boiler with 968 sq. ft. heating surface and 602 sq. ft. superheater surface fired with blast furnace gas in three tests gave efficiencies as follows: boiler 64.5; 61; 63; superheater, 9.7; 7.8; 10.3; economizers 5.2; 8.0; 9.4; total, 79.4; 76.8; 82.7. The rates of driving in lbs. water evaporated from and at 212° per sq. ft. heating surface per hour were respectively 3.45; 2.91; 3.14. The composition of the gas used in the three tests was: CO_2, 12.4; 11.4; 11.4; CO, 26.6; 27.4; 27.4; H, 4.8; 4.2; 4.0; N, 56.2; 57.0; 57.2. The chimney gases analyzed: CO_2, 23.4; 24.1, 23.3; O, 0; 0.8; 1.0; CO, 3.4; 0; 0.2. The fuel gases in these tests were accurately measured by a gasometer.

The Hohenstein Boiler, which was used by the U. S. Liquid Fuel Board in experiments with oil as fuel, is shown in Fig. 273. The lower row of tubes, which support the fire-brick roof of the furnace are 4 in. diameter; all the other tubes, which are arranged in banks inclined in opposite directions, are 2 in. The dimensions of the experimental boiler are as follows: Front and rear steam drums, 24 in.; four connecting drums, each 16 in.; mud drum, 24 in.; tubes, sixteen 4-in., 7 ft. long, 384 2-in. 9 ft. long, and 15 5-in. downtake tubes. Heating surface, 2130 sq. ft.; grate surface 50.1 sq. ft. Floor space 9 ft. wide; 11 ft. deep; height 12 ft. 7 in. Weight, boiler and fittings, with water, 54,127 lbs., without water, 46,668 lbs. Weight with water at 275 lbs. pressure, per sq. ft. of grate surface, 1080 lbs.; per sq. ft. heating surface 25.4 lbs. Air spaces in grate, 57% of grate area. Height of smoke stack above grate, 70 ft.; cross-section of smoke stack, 8.7 sq. ft. The boiler was driven, with oil as fuel, at a rate of evaporation as high as 16.7 lbs. of water per sq. ft. of heating surface per hour. The low efficiencies shown in the table below were no doubt due to the combustion chamber being far to small to allow complete combusion of the gases. At times of rapid driving great volumes of dense smoke were emitted from the

chimney. The lesson to be learned from these tests is that very low efficiency may be obtained with fuel oil when it is burned imperfectly. These tests may be compared with those of the Yarrow boiler, given

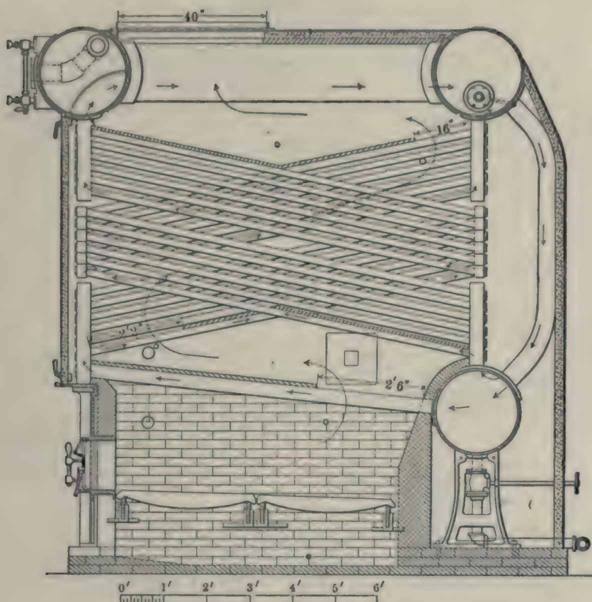


FIG. 273.—THE HOHENSTEIN BOILER.

below, to show the great improvement made in oil-burning in recent practice.

Comparative Tests with Oil Fuels. Edgar Kidwell (*Power,* May 19, 1908) gives a table of results of four tests with a Babcock & Wilcox boiler and four with a Stirling boiler, both using California oil of the same quality, 18,500 to 18,750 B.T.U. per lb., corrected for moisture, from which the following figures are taken:

Water evaporated from and at 212° per square foot per heating surface per hour.								
B. & W.	....	3.85	....	4.52	....	5.86	....	7.11
Stirling	3.58	....	4.55	....	5.68	....	6.94	....
Efficiency.								
B. & W.	....	83.06	....	80.64	....	79.37	....	73.62
Stirling	79.16	....	76.73	....	74.05	....	71.50	....
Temp. flue gases	454	438	517	464	606	525	720	622
Effy. compared with formula	−3.09	+1.17	−4.25	−0.38	−5.47	+0.09	−6.38	−4.04

TESTS OF THE HOHENSTEIN EXPERIMENTAL MARINE BOILER.

Engineering News, April 9, 1903.

COAL TRIALS.

Water per sq.ft. heating surface per hr...	3.84	4.75	5.50	7.23	10.12	12.18
Coal per sq.ft., grate, per hr...........	18.5	22.9	28.8	35.5	53.4	72.2
Equiv. evap. per lb. combustible.........	11.77	11.59	11.69	11.41	10.79	9.53
Stack temperature less fire room temp. ° F.	396	481	475	572	631	866
Loss in heat up stack, per cent..........	.....	17.7	.....	15.9	.....	28.3
Loss in heat due to incomplete combustion of C, per cent.....................	.....	5.9	.....	10.4	.....	3.4
Boiler efficiency, per cent..............	73.4	72.3	73	72.8	67.2	59.4

OIL TRIALS.

Water per sq.ft heating surface per hr....................	4.57	5.50	5.61	8.19	9.23	11.38	13.86	14.55
Equiv. evap. per lb. of oil.....	14.43	14.22	14.35	13.29	12.70	12.18	11.73	10.77
Stack temperature less fire-room temp...............	397	445	479	627	584	657	746	902
Loss in heat up stack, per cent.	13.2	14.4	15.4	15.1	17.3	20.1	24.2	28.1
Loss in heat due to incomplete combustion of C...........	2.4	0.7	0.4	1.2	7.7	6.4	1.7	1.2
Boiler efficiency.............	71.5	70.4	71.1	65.8	62.8	60.3	58.1	53.4

The formula used for comparison is $E=83-1.3(W/S-3)$ which is taken to be that of best probable performance for oil under the most favorable conditions. The explanation of the better performance of the B. & W. boiler as compared with that of the Stirling is that the furnaces were different. The Babcock & Wilcox boiler was equipped with a furnace having burners located at the bridgewall, and discharging the flame toward the front of the boiler. The Stirling boiler was equipped with burners inserted through the fire-doors and directing flame toward the bridgewall in accordance with the usual practice. The large drop in efficiency of the B. & W. boiler at the highest rate of driving is probably due to an insufficient furnace volume for burning the oil at that rate. The higher temperatures of the flue gases in the Stirling tests indicates that the combustion of the gases from the oil was not completed in the furnace.

Tests of a Boiler with Oil Fuel at Redondo, Cal. (*Power,* May 9, 1911).—The boiler was a Babcock & Wilcox, 3-pass, with 6042 sq. ft. water heating surface and 960 sq. ft. superheating surface. Hammel oil-burners were used, steam-driven, and supplied with air which was heated in brick tunnels under the furnace. The principal results were as follows, the tests being arranged in the order of the rate of

driving: (There were seven tests. No. 5 in the table gives the average results. See *Trans. A. S. M. E.*, 1911, p. 90.)

No.	1	2	3	4	5	6	7	8
Per cent of rating	72.7	94.0	109.2	109.4	125.3	132.8	163.3	195.5
Water* per lb. oil	15.35	15.66	15.75	15.47	15.15	15.37	14.37	14.12
Flue gas temp.	385	397	406	409	434	429	477	537
CO_2 in gases	12.2	13.4	14.3	13.3	13.2	14.2	13.3	12.1
O in gases	3.6	2.7	1.8	2.4	3.1	1.7	2.8	6.8
Excess air, per cent	28.7	17.7	10.6	18.5	21.2	11.3	18.5	43.0
B.T.U. per lb. oil	18,280	18,256	18,253	18,131	18,184	18,214	18,171	17,985
Density, Baumé	13.3	13.3	13.3	13.4	13.2	13.2	13.2	12.9
Moisture in oil, per cent	0.4	0.5	0.4	0.45	0.54	0.8	0.65	0.6
Water* per sq. ft. H.S. per hr.	2.54	3.24	3.77	3.78	4.32	4.58	5.63	6.74
Efficiency, per cent	81.1	82.8	83.3	82.4	80.5	81.5	76.4	75.8
Steam used by burners, per cent of total steam	1.54	2.25	2.40	2.40	2.15	2.25	2.08	2.13
Temp. of air to burners	131	134	142	134	138	140	142	142
Efficiency by formula	....	82.7	81.6	81.6	80.6	80.0	77.9	75.7
Actual efficiency, + or −	....	+0.1	+1.6	+0.8	−0.1	+1.5	−1.5	−0.1

* Evaporated from and at 212°.

The straight-line formula between tests No. 2 and No. 8 is $E = 83.2 - (W/S - 3)$. The figures in the last line show how closely the results obtained agreed with this formula. The tests are of especial interest in showing that high economy can be obtained at high rates of driving when the percentage of oxygen in the gases and the excess air supply are kept low.

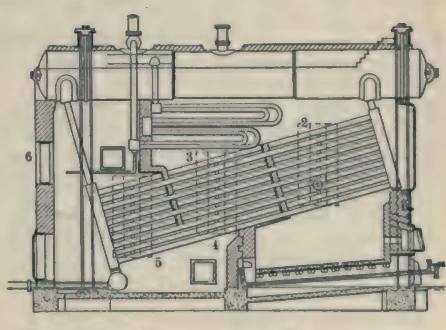


FIG. 274.—LOCATION OF PYROMETERS.

The temperature of the gases was taken by electric pyrometers at six points as shown in Fig. 274. The results were as follows:

No. of test	1	2	3	4	5	6	7	Avge.
Evap. from and at 212° per sq.ft. H.S. per hr.	2.54	3.24	3.77	3.78	4.58	5.63	6.74	4.32
Temperature of gases:								
1. Above 3d tube 1st pass	1100	1090	1160	1180	1240	1300	1600	1240
2. Top of 1st pass	640	640	700	680	780	940	1170	793
3. Top of 2d pass	570	540	620	610	650	740	820	650
4. Bottom of 2d pass	500	500	520	510	550	600	700	554
5. Bottom of 3d pass	450	450	505	495	530	570	660	523
6. In flue	385	398	409	406	429	477	538	435
Temp. of superheated steam	473	457	468	465	474	494	527	480
Degrees of superheat	92	76	87	84	93	113	144	98

Tests of a Marine Boiler with Oil Fuel.—A series of six tests of a Babcock & Wilcox marine boiler with Texas crude oil at rates of driving from 4.11 to 15.83 lbs. evaporated from and at 212° per sq. ft. of heating surface per hour is reported in Jour. Am. Soc. Naval Engineers, May, 1911. Peabody mechanical atomizers were used. The heating surface of the boiler was 2571 sq. ft., volume of furnace 217 cu. ft. Following are the principal results:

OIL TESTS OF BABCOCK & WILCOX MARINE BOILER.

Number of test Number of burners in use	1 11	2 8	3 4	4 3	5 8	6 8
Steam pressure by gage, lbs.	209.9	210.4	210.7	212	214.8	214.8
Oil pressure by gage, lbs.	191.1	188.8	175.6	131.3	153.2	171.8
Temp. of fireroom, degrees F.	71.1	75.2	70	79	79	76
Temp. of oil, degrees F.	175.3	183.4	184.0	210.1	199.0	195.7
Temp. of chim. gases, deg. F.	771	666	533	447	702	630
Percent. of moisture in steam.	.811	.710	.163	.109	.218	.165
Smoke, scale of 5	2.1	1.5	1.3	1.5	2.3	1.15
Oil per hour, pounds	2,972	1,704	1,202	666	1,922	1,947
Oil per h. per cu. ft. furnace volume, lbs.	13.69	7.85	5.54	3.07	8.86	8.97
Oil per hr. per sq. ft. heating surface, lbs.	1.156	.663	.467	.259	.747	.757
Oil per hr. per burner, lbs.	270.2	213	300.5	222	240.3	243.4
Equiv. to coal per sq.ft. of grate surface., lbs.	75.34	37.45	28.34	16.13	43.96	46.14
Equiv. evaporation from and at 212° F. per sq.ft. of heating surface, lbs.	15.83	9.53	7.35	4.11	10.56	11.69
Equiv. evaporation from and at 212° F. per cu.ft. of furnace volume, lbs.	187.60	112.87	87.06	48.70	125.10	138.53
Evaporation from and at 212° F. per lb. oil, lbs.	13.70	14.37	15.72	15.86	14.12	15.44
Chimney Gas Analysis						
Carbon dioxide (CO_2)	9.85	9.26	11.57	11.86	10.71	10.94
Oxygen (O)	6.46	7.68	4.50	4.08	5.18	4.73
Carbon monoxide (CO)	.01	.00	.04	.04	.02	.00
Nitrogen (N)	83.68	83.06	83.89	84.02	84.09	84.33
Efficiency						
Efficiency of boiler	69.29	72.68	79.50	80.21	71.41	78.08

The plotted diagram of these tests, Fig. 275, indicates that the reported efficiency of Nos. 3 and 6 may be 3 or 4 per cent too high, and that Nos. 2 and 5 are lower than they would be under the most favorable conditions. The formula of the straight line drawn from No. 4 to No. 1 is $E = 81.24 - 0.93\ (W/S - 3)$.

The analysis of the chimney gases in the best test, No. 4, showed CO_2, 11.86; O, 4.08; CO, 0.04; N, 84.02. This corresponds to 21.05 lbs. dry gas per lb. carbon. A heat balance shows the following:

		B.T.U.	Per cent.
Loss of heat in the dry gases	$21.05 \times 368 \times 0.24 =$	1,859	9.75
Loss of heat in H_2O from H in the oil	$0.109 \times 9 \times (212-79) + 970 + 0.48(447-212) =$	1,193	6.26
Utilized in making steam	$15.86 \times 970.4 =$	15,391	80.21
		18.443	96.22
Loss by radiation, heating moisture in air, incomplete combustion, and unaccounted for		747	3.78
		19,190	100.00

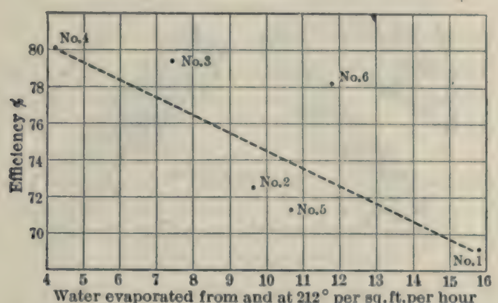


FIG. 275.—RESULTS OF TESTS WITH OIL FUEL.

Test of a Yarrow Boiler with Oil Fuel. (Proc. Inst. Nav Arch., 1912).—A modified Yarrow boiler, in which some of the upper rows of tubes on one side were removed and an equal amount of superheating surface was added above the nest of tubes, was tested with results as below. The total heating surface was 6700 sq. ft., of which 1265 sq. ft. was superheating surface. The steam pressure was about 242 lbs. The superheating ranged from 21° at the lowest rate of driving to 93° at the highest.

Evaporation from and at 212°, lbs. per sq. ft. heating surface per hr.	1.55	3.7	8.6	12.9	14.4	18.0
Evaporation per lb. of oil	16.1	16.1	15.9	15.2	15.0	14.6
Lbs. oil per sq. ft. heat. surf. per hr.	0.096	0.230	0.542	0.850	0.964	1.237
Temp. of gases between water tube and superheater	465	481	647	903	926	1121
Temp. of gases above superheater	409	432	536	685	698	828
" " above large nest of tubes	416	448	551	688	727	887
Efficiency (estimated on basis of 19,500 B.T.U. per lb. of oil) %	80.1	80.1	79.0	75.2	74.2	72.6

This test is remarkable for the high rate of evaporation reached and for the small decrease in efficiency with increased rates of driving.

The formula $E = 81.5 - 0.6\left(\frac{W}{S} - 3\right) \pm 1$ expresses the relation of the efficiency to rate of driving when the latter is above 3 lbs. per sq. ft.

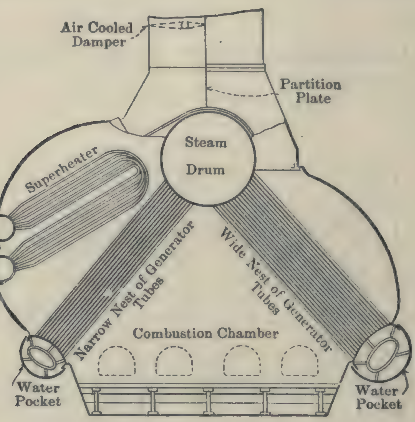


FIG. 276.—YARROW BOILER WITH SUPERHEATER.

of heating surface per hour. The cut, Fig. 276, shows the location of the superheater tubes.

Tests of Two Kinds of Tile Roof in a Heine Boiler. (Bulletin No. 34 U of Ill. Eng. Expt. Sta., 1909.)—Tests were made with a Heine boiler provided with a chain grate furnace and an extension arch built 3 ft. in front of the boiler. The setting was of the usual form. The roof of the furnace, made by tiles supported by the lower row of tubes, in four tests was of what is known as C-tile, which completely envelop the tubes, and in four other tests of T-tile, which rest upon the tubes, covering their upper surface only.

FIG. 277.—TWO KINDS OF TILE ROOF.

The coal was Vermilion Co., Ill., screenings, averaging 12.2% moisture and 14.6% ash by analysis. In the boiler tests the ash and refuse averaged in the C-tile tests 19.80% and in the T-tile tests 15.75%. The differences in handling the fire in the two tests as shown by the difference in percentage of refuse and in the CO_2 in the gases, which latter is far too low for good economy, go far to account for the difference of 3% in efficiency. With the C-tile nearly

	C-Tile.	T-Tile.	Difference.
Temp. front part of furnace	2066	1883	183
" over bridge-wall	2151	1851	300
" forward part of combustion chamber.	1968	1597	371
" rear part of combustion chamber	1642	1384	258
" in uptake	558	468	90
Efficiency, (C-tile, 64.4 to 66.3, T-tile, 67.5 to 69.4) Av. of 4	65.6	68.6	3
CO_2 in flue gases	6.8	7.5	
Smoke	None	Very little	
Water evap. from and at 212° per sq. ft. H. S. per hr	3.68	3.72	

the whole heating surface of the lower row of tubes was protected from impingement by the hot gases, and effectively shielded from radiation from the fuel bed and the particles of incandescent carbon in the gases.

It was evident, says the report, that had higher capacity been demanded, trouble with black smoke would have resulted with the T-tile roof. In that case it is likely that the C-tile roof would have shown the higher efficiency.

Superheated Steam in Locomotive Service.—Publication No. 127 of the Carnegie Institution of Washington, a book of 144 pages, contains the full record of a research by Dr. W. F. M. Goss, made in the laboratory of Purdue University, of the operation of two locomotives, one with saturated and the other with superheated steam. The results are reviewed by Dr. Goss in Bulletin 57 of the University of Illinois Engineering Experiment Station, 1912. The following is a summary of his conclusions:

Superheated steam may be successfully used in locomotive service without involving mechanism which is unduly complicated or difficult to maintain.

The various details in contact with the highly heated steam, such as the superheater, piping, valves, pistons, and rod packing, give practically no trouble in maintenance.

Superheating materially reduces the consumption of water and fuel and increases the power capacity of the locomotive.

The combined boiler and superheater tested contains 934 sq. ft. of water-heating surface and 193 sq. ft. of superheating surface; it delivers steam which is superheated approximately 150°. The amount of superheat diminishes when the boiler-pressure is increased, and increases when the rate of evaporation is increased, the precise relation being,

$$T = 123 - 0.265\,P + 7.28\,H$$

where T represents the superheat in degrees F., P the boiler-pressure by gage, and H the equivalent evaporation per foot of water-heating surface per hour.

The evaporation of the combined boiler and superheater tested is

$$E = 11.706 - 0.214\,H$$

where E is the equivalent evaporation per pound of fuel and H is the equivalent evaporation per hour per square foot of water-heating and superheating surface.*

The ratio of the heat absorbed per square foot of superheating surface to that absorbed per square foot of water-heating surface ranges from 0.34 to 0.53, increasing as the rate of evaporation is increased.

When the boiler and superheater are operated at normal maximum power, and when they are served with Pennsylvania or West Virginia coal of good quality, the available heat supplied is accounted for approximately as follows:

	Per cent
Absorbed by water	52
Absorbed by steam in superheater	5
Utilized	57
Lost in vaporizing moisture in coal	5
Lost in CO	1
Lost through high temperature of escaping gases	14
Lost in the form of sparks and cinders	12
Lost through grate	4
Lost through radiation, leakage, and unaccounted for	7

Neither the steam nor the coal consumption is materially affected by considerable changes in boiler-pressure, a fact which justifies the use of comparatively low pressures in connection with superheating.

For maximum cylinder efficiency with steam superheated 150°, when the boiler-pressure is 120, the best cut-off is approximately 50 per cent of the stroke, diminishing as the pressure is raised, until at 240 lbs. it becomes 20 per cent.

The saving in water consumption and in coal consumption per unit power developed, which was effected by the superheatng locomotive, in comparison with the saturated-steam locomotive, is as follows:

Boiler pressure	120	160	200	240
Water per I.H.P. hr. saturated	29.1	26.6	25.5	24.7
" " " superheated	23.8	22.3	21.6	22.6
Gain per cent	18	16	15	9
Coal per I.H.P. hr. saturated	4.00	3.59	3.43	3.31
" " " superheated	3.31	3.08	2.97	3.12
Gain per cent	17	14	13	6

The power capacity of the superheating locomotive is greater than that of the saturated-steam locomotive.

* Assuming 14,000 B.T.U. per pound as the heating value of the fuel, this formula is equivalent to Efficiency $= 77.6 - 1.5(W/S - 3)$, which may be compared to the several straight line formulæ given in Chap. IX.

The number of superheating locomotives in Europe is now (1911) reported as 7000 and that the number in this country, in service or under order, is approximately 2000.

Tests of Boilers with Natural Gas as Fuel.—J. M. Whitham (Trans. A. S. M. E., 1905) reports the results of several tests of water-tube boilers with natural gas. The following is a condensed statement of the results:

Kind of Boiler............	Cook Vertical.		Heine.			Cahall Vert.	
Rated H. P. of boilers..	1500	1500	200	200	200	300	300
H. P. developed.......	1642	1507	155	218	258	340	260
Temperature at chimney	521	494	386	450	465	406	374
Gas pressure at burners, oz	6.9	6.4	.....	.....	.....	4.8	7 to 30
Cu. ft. of gas per boiler H. P.-hour..........	44.9*	41.0*	46.0†	40.7†	38.3†	42.3	34
Boiler efficiency, %....	72.7	....	65.8	.....	74.9	....	..

* Reduced to 4 oz. pressure and 62° F.
† Reduced to atmos. press. and 32° F.

Mr. Whitham found that as good economy was obtained with a blue as with a white or straw flame, and no better. Greater capacity may be made with a straw white than with a blue flame. A writer in *Power*, Oct. 22, 1912, commenting on this says "it is generally conceded that the blue flame indicates more efficient combustion, a higher temperature and a superior performance, other things being equal." Things that are "generally conceded" are sometimes wrong, and this is an instance. A blue flame indicates combustion of a thorough mixture of air and gas. The air supply may be just sufficient to make complete combustion, in which case the temperature at the point of the flame will be considerably over 3000° F., or it may be greatly in excess, in which case the temperature will be lower. A white flame indicates delayed combustion, the white color being due to particles of incandescent carbon, but these particles, when they reach the margin of the flame and there come in contact with heated air are burned to invisible carbon dioxide. Whether the flame is blue or white, whether combustion is instantaneous or delayed, the same quantity of fuel burned will generate the same quantity of heat, and if the air supply is the same in both cases the boiler efficiency should be the same. But the efficiency will be decreased with either the blue or the white flame if the air supply is excessive, and in case of the white flame if it is allowed to touch the surface of the boiler before the combustion is complete, so that the white-hot carbon particles are cooled and become particles of soot instead of being burned.

CHAPTER XVIII.*

PROPERTIES OF WATER AND OF STEAM—FACTORS OF EVAPORATION—CHIMNEYS.

WATER

Weight of Water at Different Temperatures.—The weight of water at maximum density, 39.1°, is generally taken at the figure given by Rankine, 62.425 lbs. per cu. ft. Some authorities give as low as 62.379. The figure 62.5 commonly given is approximate. The highest authoritative figure is 62.425. At 62° F. the figures range from 62.291 to 62.360. The figure 62.355 is generally accepted as the most accurate.

At 32° F. figures given by different writers range from 62.379 to 62.418. Clark gives the latter figure and Hamilton Smith, Jr. (from Rosetti), gives 62.416.

Weight of Water at Temperatures above 200° F. (Landolt and Börnstein's Tables, 1905.)

Deg. F.	Pounds per Cubic Foot.	Deg. F.	Pounds per Cubic Foot.	Deg. F.	Pounds per Cubic Foot.	Deg. F.	Pounds per Cubic Foot.	Deg. F.	Pounds per Cubic Foot.	Deg. F.	Lbs. Per Cubic Foot.
200	60.12	270	58.26	340	55.94	410	53.0	480	49.7	550	45.6
210	59.88	280	57.96	350	55.57	420	52.6	490	49.2	560	44.9
220	59.63	290	57.65	360	55.18	430	52.2	500	48.7	570	44.1
230	59.37	300	57.33	370	54.78	440	51.7	510	48.1	580	43.3
240	59.11	310	57.00	380	54.36	450	51.2	520	47.6	590	42.6
250	58.83	320	56.66	390	53.94	460	50.7	530	47.0	600	41.8
260	58.55	330	56.30	400	53.5	470	52.2	540	46.3		

Weight of Water per Cubic Foot, from 32° to 212° F., and heat-units per pound, reckoned above 32° F.: The figures for weight of water in the following table, made by interpolating the table given by Clark as calculated from Rankine's formula, with corrections for apparent errors, was published by the author in 1884, Trans. A.

* This chapter is chiefly compiled from the author's "Mechanical Engineers' Pocketbook."

S. M. E., vi. 90. The figures for heat-units are from Marks and Davis's Steam Tables, 1909. (For heat-units above 212° see Steam Tables.)

Temperature, Deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Temperature, Deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Temperature, Deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Temperature, Deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.
32	62.42	0	78	62.25	46.04	123	61.68	90.90	168	60.81	135.86
33	62.42	1.01	79	62.24	47.04	124	61.67	91.90	169	60.79	136.86
34	62.42	2.02	80	62.23	48.03	125	61.65	92.90	170	60.77	137.87
35	62.42	3.02	81	62.22	49.03	126	61.63	93.90	171	60.75	138.87
36	62.42	4.03	82	62.21	50.03	127	61.61	94.89	172	60.73	139.87
37	62.42	5.04	83	62.20	51.02	128	61.60	95.89	173	60.70	140.87
38	62.42	6.04	84	62.19	52.02	129	61.58	96.89	174	60.68	141.87
39	62.42	7.05	85	62.18	53.02	130	61.56	97.89	175	60.66	142.87
40	62.42	8.05	86	62.17	54.01	131	61.54	98.89	176	60.64	143.87
41	62.42	9.05	87	62.16	55.01	132	61.52	99.88	177	60.62	144.88
42	62.42	10.06	88	62.15	56.01	133	61.51	100.88	178	60.59	145.88
43	62.42	11.06	89	62.14	57.00	134	61.49	101.88	179	60.57	146.88
44	62.42	12.06	90	62.13	58.00	135	61.47	102.88	180	60.55	147.88
45	62.42	13.07	91	62.12	59.00	136	61.45	103.88	181	60.53	148.88
46	62.42	14.07	92	62.11	60.00	137	61.43	104.87	182	60.50	149.89
47	62.42	15.07	93	62.10	60.99	138	61.41	105.87	183	60.48	150.89
48	62.41	16.07	94	62.09	61.99	139	61.39	106.87	184	60.46	151.89
49	62.41	17.08	95	62.08	62.99	140	61.37	107.87	185	60.44	152.89
50	62.41	18.08	96	62.07	63.98	141	61.36	108.87	186	60.41	153.89
51	62.41	19.08	97	62.06	64.98	142	61.34	109.87	187	60.39	154.90
52	62.40	20.08	98	62.05	65.98	143	61.32	110.87	188	60.37	155.90
53	62.40	21.08	99	62.03	66.97	144	61.30	111.87	189	60.34	156.90
54	62.40	22.08	100	62.02	67.97	145	61.28	112.86	190	60.32	157.91
55	62.39	23.08	101	62.01	68.97	146	61.26	113.86	191	60.29	158.91
56	62.39	24.08	102	62.00	69.96	147	61.24	114.86	192	60.27	159.91
57	62.39	25.08	103	61.99	70.96	148	61.22	115.86	193	60.25	160.91
58	62.38	26.08	104	61.97	71.96	149	61.20	116.86	194	60.22	161.92
59	62.38	27.08	105	61.96	72.95	150	61.18	117.86	195	60.20	162.92
60	62.37	28.08	106	61.95	73.95	151	61.16	118.86	196	60.17	163.92
61	62.37	29.08	107	61.93	74.95	152	61.14	119.86	197	60.15	164.93
62	62.36	30.08	108	61.92	75.95	153	61.12	120.86	198	60.12	165.93
63	62.36	31.07	109	61.91	76.94	154	61.10	121.86	199	60.10	166.94
64	62.35	32.07	110	61.89	77.94	155	61.08	122.86	200	60.07	167.94
65	62.34	33.07	111	61.88	78.94	156	61.06	123.86	201	60.05	168.94
66	62.34	34.07	112	61.86	79.93	157	61.04	124.86	202	60.02	169.95
67	62.33	35.07	113	61.85	80.93	158	61.02	125.86	203	60.00	170.95
68	62.33	36.07	114	61.83	81.93	159	61.00	126.86	204	59.97	171.96
69	62.32	37.06	115	61.82	82.92	160	60.98	127.86	205	59.95	172.96
70	62.31	38.06	116	61.80	83.92	161	60.96	128.86	206	59.92	173.97
71	62.31	39.06	117	61.78	84.92	162	60.94	129.86	207	59.89	174.97
72	62.30	40.05	118	61.77	85.92	163	60.92	130.86	208	59.87	175.98
73	62.29	41.05	119	61.75	86.91	164	60.90	131.86	209	59.84	176.98
74	62.28	42.05	120	61.74	87.91	165	60.87	132.86	210	59.82	177.99
75	62.28	43.05	121	61.72	88.91	166	60.85	133.86	211	59.79	178.99
76	62.27	43.04	122	61.70	89.91	167	60.83	134.86	212	59.76	180.00
77	62.26	45.04									

Later authorities give figures for the weight of water which differ in the second decimal place only from those given above, as follows:

Temp. F.....	40	50	60	70	80	90
Lbs. per cu. ft.	62.43	62.42	62.37	62.30	62.22	62.11
Temp. F.....	100	110	120	130	140	150
Lbs. per cu. ft.	62.00	61.86	61.71	61.55	61.38	61.18
Temp. F.....	160	170	180	190	200	210
Lbs. per cu. ft.	61.00	60.80	60.50	60.36	60.12	59.88

Steam.

The Temperature of Steam in contact with water depends upon the pressure under which it is generated. At the ordinary atmospheric pressure (14.7 lbs. per sq. in.) its temperature is 212° F. As the pressure is increased, as by the steam being generated in a closed vessel, its temperature, and that of the water in its presence, increases.

Saturated Steam is steam of the temperature due to its pressure —not superheated.

Superheated Steam is steam heated to a temperature above that due to its pressure.

Dry Steam is steam which contains no moisture. It may be either saturated or superheated.

Wet Steam is steam containing intermingled moisture, mist, or spray. It has the same temperature as dry saturated steam of the same pressure.

Water introduced into the presence of superheated steam will flash into vapor until the temperature of the steam is reduced to that due to its pressure. Water in the presence of saturated steam has the same temperature as the steam. Should cold water be introduced, lowering the temperature of the whole mass, some of the steam will be condensed, reducing the pressure and temperature of the remainder, until an equilibrium is established.

The total heat in steam (above 32°) includes three elements:

1st. The heat required to raise the temperature of the water to the temperature of the steam.

2d. The heat required to evaporate the water at that temperature, called internal latent heat.

3d. The latent heat of volume, or the external work done by the steam in making room for itself against the pressure of the superincumbent atmosphere (or surrounding steam if inclosed in a vessel).

The sum of the last two elements is called the latent heat of steam.

Heat Required to Generate 1 Pound of Steam at 212°.—

		Heat-units.
Sensible heat, to raise 1 lb. water from 32° to 212° =		180.0
Latent heat, 1, of the formation of span at 212°... =	897.6	
2, of expansion against the atmospheric pressure, 2116.4 lbs. per sq. ft. × 26.79 cu.ft. = 55,786 foot-pounds ÷ 778 .... =	72.8	970.4
Total heat above 32°		1150.4

Identification of Dry Steam by Appearance of a Jet.—Prof. Denton (Trans. A. S. M. E., vol. x) found that jets of steam show unmistakable change of appearance to the eye when steam varies less than 1 per cent from the condition of saturation either in the direction of wetness or superheating.

If a jet of steam flow from a boiler into the atmosphere under circumstances such that very little loss of heat occurs through radiation, etc., and the jet be transparent close to the orifice, or be even a grayish-white color, the steam may be assumed to be so nearly dry that no portable condensing calorimeter will be capable of measuring the amount of water in the steam. If the jet be strongly white, the amount of water may be roughly judged up to about 2 per cent, but beyond this a calorimeter only can determine the exact amount of moisture.

PROPERTIES OF SATURATED STEAM.

(Condensed from Marks and Davis's Steam Tables and Diagrams, 1909, by permission of the publishers, Longmans, Green & Co.)

Vacuum, Inches of Mercury.	Absolute Pressures, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat Above 32° F.		Latent Heat L, = H − h. Heat-Units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cu. Ft. Steam, Lb.
			In the Water h Heat-units.	In the Steam. H Heat-units.			
29.74	0.0886	32	0.00	1073.4	1073.4	3294	0.000304
29.67	0.1217	40	8.05	1076.9	1068.9	2438	0.000410
29.56	0.1780	50	18.08	1081.4	1063.3	1702	0.000587
29.40	0.2562	60	28.08	1085.9	1057.8	1208	0.000828
29.18	0.3626	70	38.06	1090.3	1052.3	871	0.001148
28.89	0.505	80	48.03	1094.8	1046.7	636.8	0.001570
28.50	0.696	90	58.00	1099.2	1041.2	469.3	0.002131
28.00	0.946	100	67.97	1103.6	1035.6	350.8	0.002851
27.88	1	101.83	69.8	1104.4	1034.6	333.0	0.00300
25.85	2	126.15	94.0	1115.0	1021.0	173.5	0.00576
23.81	3	141.52	109.4	1121.6	1012.3	118.5	0.00845
21.78	4	153.01	120.9	1126.5	1005.7	90.5	0.01107
19.74	5	162.28	130.1	1130.5	1000.3	73.33	0.01364
17.70	6	170.06	137.9	1133.7	995.8	61.89	0.01616
15.67	7	176.85	144.7	1136.5	991.8	53.56	0.01867
13.63	8	182.86	150.8	1139.0	988.2	47.27	0.02115
11.60	9	188.27	156.2	1141.1	985.0	42.36	0.02361
9.56	10	193.22	161.1	1143.1	982.0	38.38	0.02606
7.52	11	197.75	165.7	1144.9	979.2	35.10	0.02849
5.49	12	201.96	169.9	1146.5	976.6	32.36	0.03090
3.45	13	205.87	173.8	1148.0	974.2	30.03	0.03330
1.42	14	209.55	177.5	1149.4	971.9	28.02	0.03569
lbs. gauge	14.70	212	180.0	1150.4	970.4	26.79	0.03732
0.3	15	213.0	181.0	1150.7	969.7	26.27	0.03806
1.3	16	216.3	184.4	1152.0	967.6	24.79	0.04042
2.3	17	219.4	187.5	1153.1	965.6	23.38	0.04277
3.3	18	222.4	190.5	1154.2	963.7	22.16	0.04512
4.3	19	225.2	193.4	1155.2	961.8	21.07	0.04746
5.3	20	228.0	196.1	1156.2	960.0	20.08	0.04980
6.3	21	230.6	198.8	1157.1	958.3	19.18	0.05213
7.3	22	233.1	201.3	1158.0	956.7	18.37	0.05445
8.3	23	235.5	203.8	1158.8	955.1	17.62	0.05676
9.3	24	237.8	206.1	1159.6	953.5	16.93	0.05907
10.3	25	240.1	208.4	1160.4	952.0	16.30	0.0614
11.3	26	242.2	210.6	1161.2	950.6	15.72	0.0636
12.3	27	244.4	212.7	1161.9	949.2	15.18	0.0659
13.3	28	246.4	214.8	1162.6	947.8	14.67	0.0682
14.3	29	248.4	216.8	1163.2	946.4	14.19	0.0705
15.3	30	250.3	218.8	1163.9	945.1	13.74	0.0728
16.3	31	252.2	220.7	1164.5	943.8	13.32	0.0751
17.3	32	254.1	222.6	1165.1	942.5	12.93	0.0773
18.3	33	255.8	224.4	1165.7	941.3	12.57	0.0795
19.3	34	257.6	226.2	1166.3	940.1	12.22	0.0818
20.3	35	259.3	227.9	1166.8	938.9	11.89	0.0841
21.3	36	261.0	229.6	1167.3	937.7	11.58	0.0863

PROPERTIES OF SATURATED STEAM.—*Continued.*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat Above 32° F. In the Water. h Heat-units.	Total Heat Above 32° F. In the Steam. H Heat-units.	Latent Heat, $L = H - h$. Heat-units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cubic Ft. Steam, Lb.
22.3	37	262.6	231.3	1167.8	936.6	11.29	0.0886
23.3	38	264.2	232.9	1168.4	935.5	11.01	0.0908
24.3	39	265.8	234.5	1168.9	934.4	10.74	0.0931
25.3	40	267.3	236.1	1169.4	933.3	10.49	0.0953
26.3	41	268.7	237.6	1169.8	932.2	10.25	0.0976
27.3	42	270.2	239.1	1170.3	931.2	10.02	0.0998
28.3	43	271.7	240.5	1170.7	930.2	9.80	0.1020
29.3	44	273.1	242.0	1171.2	929.2	9.59	0.1043
30.3	45	274.5	243.4	1171.6	928.2	9.39	0.1065
31.3	46	275.8	244.8	1172.0	927.2	9.20	0.1087
32.3	47	277.2	246.1	1172.4	926.3	9.02	0.1109
33.3	48	278.5	247.5	1172.8	925.3	8.84	0.1131
34.3	49	279.8	248.8	1173.2	924.4	8.67	0.1153
35.3	50	281.0	250.1	1173.6	923.5	8.51	0.1175
36.3	51	282.3	251.4	1174.0	922.6	8.35	0.1197
37.3	52	283.5	252.6	1174.3	921.7	8.20	0.1219
38.3	53	284.7	253.9	1174.7	920.8	8.05	0.1241
39.3	54	285.9	255.1	1175.0	919.9	7.91	0.1263
40.3	55	287.1	256.3	1175.4	919.0	7.78	0.1285
41.3	56	288.2	257.5	1175.7	918.2	7.65	0.1307
42.3	57	289.4	258.7	1176.0	917.4	7.52	0.1329
43.3	58	290.5	259.8	1176.4	916.5	7.40	0.1350
44.3	59	291.6	261.0	1176.7	915.7	7.28	0.1372
45.3	60	292.7	262.1	1177.0	914.9	7.17	0.1394
46.3	61	293.8	263.2	1177.3	914.1	7.06	0.1416
47.3	62	294.9	264.3	1177.6	913.3	6.95	0.1438
48.3	63	295.9	265.4	1177.9	912.5	6.85	0.1460
49.3	64	297.0	266.4	1178.2	911.8	6.75	0.1482
50.3	65	298.0	267.5	1178.5	911.0	6.65	0.1503
51.3	66	299.0	268.5	1178.8	910.2	6.56	0.1525
52.3	67	300.0	269.6	1179.0	909.5	6.47	0.1547
53.3	68	301.0	270.6	1179.3	908.7	6.38	0.1569
54.3	69	302.0	271.6	1179.6	908.0	6.29	0.1590
55.3	70	302.9	272.6	1179.8	907.2	6.20	0.1612
56.3	71	303.9	273.6	1180.1	906.5	6.12	0.1634
57.3	72	304.8	274.5	1180.4	905.8	6.04	0.1656
58.3	73	305.8	275.5	1180.6	905.1	5.96	0.1678
59.3	74	306.7	276.5	1180.9	904.4	5.89	0.1699
60.3	75	307.6	277.4	1181.1	903.7	5.81	0.1721
61.3	76	308.5	278.3	1181.4	903.0	5.74	0.1743
62.3	77	309.4	279.3	1181.6	902.3	5.67	0.1764
63.3	78	310.3	280.2	1181.8	901.7	5.60	0.1786
64.3	79	311.2	281.1	1182.1	901.0	5.54	0.1808
65.3	80	312.0	282.0	1182.3	900.3	5.47	0.1829
66.3	81	312.9	282.9	1182.5	899.7	5.41	0.1851
67.3	82	313.8	283.8	1182.8	899.0	5.34	0.1873
68.3	83	314.6	284.6	1183.0	898.4	5.28	0.1894
69.3	84	315.4	285.5	1183.2	897.7	5.22	0.1915
70.3	85	316.3	286.3	1183.4	897.1	5.16	0.1937

PROPERTIES OF SATURATED STEAM—*Continued.*

Gauge Pressure, Lbs. per Sq. In.	Absolute Pressure, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat Above 32° F.		Latent Heat, $L = H - h$ Heat-units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cubic Ft. Steam, Lb.
			In the Water. h Heat-units.	In the Steam. H Heat-units.			
71.3	86	317.1	287.2	1183.6	896.4	5.10	0.1959
72.3	87	317.9	288.0	1183.8	895.8	5.05	0.1980
73.3	88	318.7	288.9	1184.0	895.2	5.00	0.2001
74.3	89	319.5	289.7	1184.2	894.6	4.94	0.2023
75.3	90	320.3	290.5	1184.4	893.9	4.89	0.2044
76.3	91	321.1	291.3	1184.6	893.3	4.84	0.2065
77.3	92	321.8	292.1	1184.8	892.7	4.79	0.2087
78.3	93	322.6	292.9	1185.0	892.1	4.74	0.2109
79.3	94	323.4	293.7	1185.2	891.5	4.69	0.2130
80.3	95	324.1	294.5	1185.4	890.9	4.65	0.2151
81.3	96	324.9	295.3	1185.6	890.3	4.60	0.2172
82.3	97	325.6	296.1	1185.8	889.7	4.56	0.2193
83.3	98	326.4	296.8	1186.0	889.2	4.51	0.2215
84.3	99	327.1	297.6	1186.2	888.6	4.47	0.2237
85.3	100	327.8	298.3	1186.3	888.0	4.429	0.2258
87.3	102	329.3	299.8	1186.7	886.9	4.347	0.2300
89.3	104	330.7	301.3	1187.0	885.8	4.268	0.2343
91.3	106	332.0	302.7	1187.4	884.7	4.192	0.2386
93.3	108	333.4	304.1	1187.7	883.6	4.118	0.2429
95.3	110	334.8	305.5	1188.0	882.5	4.047	0.2472
97.3	112	336.1	306.9	1188.4	881.4	3.978	0.2514
99.3	114	337.4	308.3	1188.7	880.4	3.912	0.2556
101.3	116	338.7	309.6	1189.0	879.3	3.848	0.2599
103.3	118	340.0	311.0	1189.3	878.3	3.786	0.2641
105.3	120	341.3	312.3	1189.6	877.2	3.726	0.2683
107.3	122	342.5	313.6	1189.8	876.2	3.668	0.2726
109.3	124	343.8	314.9	1190.1	875.2	3.611	0.2769
111.3	126	345.0	316.2	1190.4	874.2	3.556	0.2812
113.3	128	346.2	317.4	1190.7	873.3	3.504	0.2854
115.3	130	347.4	318.6	1191.0	872.3	3.452	0.2897
117.3	132	348.5	319.9	1191.2	871.3	3.402	0.2939
119.3	134	349.7	321.1	1191.5	870.4	3.354	0.2981
121.3	136	350.8	322.3	1191.7	869.4	3.308	0.3023
123.3	138	352.0	323.4	1192.0	868.5	3.263	0.3065
125.3	140	353.1	324.6	1192.2	867.6	3.219	0.3107
127.3	142	354.2	325.8	1192.5	866.7	3.175	0.3150
129.3	144	355.3	326.9	1192.7	865.8	3.133	0.3192
131.3	146	356.3	328.0	1192.9	864.9	3.092	0.3234
133.3	148	357.4	329.1	1193.2	864.0	3.052	0.3276
135.5	150	358.5	330.2	1193.4	863.2	3.012	0.3320
137.3	152	359.5	331.4	1193.6	862.3	2.974	0.3362
139.3	154	360.5	332.4	1193.8	861.4	2.938	0.3404
141.3	156	361.6	333.5	1194.1	860.6	2.902	0.3446
143.3	158	362.6	334.6	1194.3	859.7	2.868	0.3488
145.3	160	363.6	335.6	1194.5	858.8	2.834	0.3529
147.3	162	364.6	336.7	1194.7	858.0	2.801	0.3570
149.3	164	365.6	337.7	1194.9	857.2	2.769	0.3612
151.3	166	366.5	338.7	1195.1	856.4	2.737	0.3654
153.3	168	367.5	339.7	1195.3	855.5	2.706	0.3696

PROPERTIES OF SATURATED STEAM.—*Continued.*

Gage Pressure, Lbs. per Sq. In.	Absolute Pressure, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat Above 32° F. In the Water. h Heat-units.	Total Heat Above 32° F. In the Steam. H Heat-units.	Latent Heat, $L = H - h$. Heat-units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cubic Ft. Steam, Lb.
155.3	170	368.5	340.7	1195.4	854.7	2.675	0.3738
157.3	172	369.4	341.7	1195.6	853.9	2.645	0.3780
159.3	174	370.4	342.7	1195.8	853.1	2.616	0.3822
161.3	176	371.3	343.7	1196.0	852.3	2.588	0.3864
163.3	178	372.2	344.7	1196.2	851.5	2.560	0.3906
165.3	180	373.1	345.6	1196.4	850.8	2.533	0.3948
167.3	182	374.0	346.6	1196.6	850.0	2.507	0.3989
169.3	184	374.9	347.6	1196.8	849.2	2.481	0.4031
171.3	186	375.8	348.5	1196.9	848.4	2.455	0.4073
173.3	188	376.7	349.4	1197.1	847.7	2.430	0.4115
175.3	190	377.6	350.4	1197.3	846.9	2.406	0.4157
177.3	192	378.5	351.3	1197.4	846.1	2.381	0.4199
179.3	194	379.3	352.2	1197.6	845.4	2.358	0.4241
181.3	196	380.2	353.1	1197.8	844.7	2.335	0.4283
183.3	198	381.0	354.0	1197.9	843.9	2.312	0.4325
185.3	200	381.9	354.9	1198.1	843.2	2.290	0.437
190.3	205	384.0	357.1	1198.5	841.4	2.237	0.447
195.3	210	386.0	359.2	1198.8	839.6	2.187	0.457
200.3	215	388.0	361.4	1199.2	837.9	2.138	0.468
205.3	220	389.9	363.4	1199.6	836.2	2.091	0.478
210.3	225	391.9	365.5	1199.9	834.4	2.046	0.489
215.3	230	393.8	367.5	1200.2	832.8	2.004	0.499
220.3	235	395.6	369.4	1200.6	831.1	1.964	0.509
225.3	240	397.4	371.4	1200.9	829.5	1.924	0.520
230.3	245	399.3	373.3	1201.2	827.9	1.887	0.530
235.3	250	401.1	375.2	1201.5	826.3	1.850	0.541
245.3	260	404.5	378.9	1202.1	823.1	1.782	0.561
255.3	270	407.9	382.5	1202.6	820.1	1.718	0.582
265.3	280	411.2	386.0	1203.1	817.1	1.658	0.603
275.3	290	414.4	389.4	1203.6	814.2	1.602	0.624
285.3	300	417.5	392.7	1204.1	811.3	1.551	0.645
295.3	310	420.5	395.9	1204.5	808.5	1.502	0.666
305.3	320	423.4	399.1	1204.9	805.8	1.456	0.687
315.3	330	426.3	402.2	1205.3	803.1	1.413	0.708
325.3	340	429.1	405.3	1205.7	800.4	1.372	0.729
335.3	350	431.9	408.2	1206.1	797.8	1.334	0.750
345.3	360	434.6	411.2	1206.4	795.3	1.298	0.770
355.3	370	437.2	414.0	1206.8	792.8	1.264	0.791
365.3	380	439.9	416.8	1207.1	790.3	1.231	0.812
375.3	390	442.3	419.5	1207.4	787.9	1.200	0.833
385.3	400	444.8	422	1208	786	1.17	0.86
435.3	450	456.5	435	1209	774	1.04	0.96
485.3	500	467.3	448	1210	762	0.93	1.08
535.3	550	477.3	459	1210	751	0.83	1.20
585.3	600	486.6	469	1210	741	0.76	1.32

PROPERTIES OF SUPERHEATED STEAM.

(Condensed from Marks and Davis's Steam Tables and Diagrams.)

v = specific volume in cu.ft. per lb., h = total heat, from water at 32° F. in B.T.U. per lb.

Press. Abs. Lbs. per Sq. In.	Temp. Sat. Steam.		Degrees of Superheat.									
			0	20	50	100	150	200	250	300	400	500
20	228.0	v	20.08	20.73	21.69	23.25	24.80	26.33	27.85	29.37	32.39	35.40
		h	1156.2	1165.7	1179.9	1203.5	1227.1	1250.6	1274.1	1297.6	1344.8	1392.2
40	267.3	v	10.49	10.83	11.33	12.13	12.93	13.70	14.48	15.25	16.78	18.30
		h	1169.4	1179.3	1194.0	1218.4	1242.4	1266.4	1290.3	1314.1	1361.6	1409.3
60	292.7	v	7.17	7.40	7.75	8.30	8.84	9.36	9.89	10.41	11.43	12.45
		h	1177.0	1187.3	1202.6	1227.6	1252.1	1276.4	1300.4	1324.3	1372.2	1420.0
80	312.0	v	5.47	5.65	5.92	6.34	6.75	7.17	7.56	7.95	8.72	9.49
		h	1182.3	1193.0	1208.8	1234.3	1259.0	1283.6	1307.8	1331.9	1379.8	1427.9
100	327.8	v	4.43	4.58	4.79	5.14	5.47	5.80	6.12	6.44	7.07	7.69
		h	1186.3	1197.5	1213.8	1239.7	1264.7	1289.4	1313.6	1337.8	1385.9	1434.1
120	341.3	v	3.73	3.85	4.04	4.33	4.62	4.89	5.17	5.44	5.96	6.48
		h	1189.6	1201.1	1217.9	1244.1	1269.3	1294.1	1318.4	1342.7	1391.0	1439.4
140	353.1	v	3.22	3.32	3.49	3.75	4.00	4.24	4.48	4.71	5.16	5.61
		h	1192.2	1204.3	1221.4	1248.0	1273.3	1298.2	1322.6	1346.9	1395.4	1443.8
160	363.6	v	2.83	2.93	3.07	3.30	3.53	3.74	3.95	4.15	4.56	4.95
		h	1194.5	1207.0	1224.5	1251.3	1276.8	1301.7	1326.2	1350.6	1399.3	1447.9
180	373.1	v	2.53	2.62	2.75	2.96	3.16	3.35	3.54	3.72	4.09	4.44
		h	1196.4	1209.4	1227.2	1254.3	1279.9	1304.8	1329.5	1353.9	1402.7	1451.4
200	381.9	v	2.29	2.37	2.49	2.68	2.86	3.04	3.21	3.38	3.71	4.03
		h	1198.1	1211.6	1229.8	1257.1	1282.6	1307.7	1332.4	1357.0	1405.9	1454.7
220	389.9	v	2.09	2.16	2.28	2.45	2.62	2.78	2.94	3.10	3.40	3.69
		h	1199.6	1213.6	1232.2	1259.6	1285.2	1310.3	1335.1	1359.8	1408.8	1457.7
240	397.4	v	1.92	1.99	2.09	2.26	2.42	2.57	2.71	2.85	3.13	3.40
		h	1200.9	1215.4	1234.3	1261.9	1287.6	1312.8	1337.6	1362.3	1411.5	1460.5
260	404.5	v	1.78	1.84	1.94	2.10	2.24	2.39	2.52	2.65	2.91	3.16
		h	1202.1	1217.1	1236.4	1264.1	1289.9	1315.1	1340.0	1364.7	1414.0	1463.2
280	411.2	v	1.66	1.72	1.81	1.95	2.09	2.22	2.35	2.48	2.72	2.95
		h	1203.1	1218.7	1238.4	1266.2	1291.9	1317.2	1342.2	1367.0	1416.4	1465.7
300	417.5	v	1.55	1.60	1.69	1.83	1.96	2.09	2.21	2.33	2.55	2.77
		h	1204.1	1220.2	1240.3	1268.2	1294.0	1319.3	1344.3	1369.2	1418.6	1468.0
350	431.9	v	1.33	1.38	1.46	1.58	1.70	1.81	1.92	2.02	2.22	2.41
		h	1206.1	1223.9	1244.6	1272.7	1298.7	1324.1	1349.3	1374.3	1424.0	1473.7
400	444.8	v	1.17	1.21	1.28	1.40	1.50	1.60	1.70	1.79	1.97	2.14
		h	1207.7	1227.2	1248.6	1276.9	1303.0	1328.6	1353.9	1379.1	1429.0	1478.9
450	456.5	v	1.04	1.08	1.14	1.25	1.35	1.44	1.53	1.61	1.77	1.93
		h	1209	1231	1252	1281	1307	1333	1358	1383	1434	1484
500	467.3	v	0.93	0.97	1.03	1.13	1.22	1.31	1.39	1.47	1.62	1.76
		h	1210	1233	1256	1285	1311	1337	1362	1388	1438	1489

Factors of Evaporation.—The figures in the table on pp. 667-670 are calculated from the formula $F = (H - h) \div 970.4$, in which H is the total heat above 32° of 1 lb. of steam of the observed pressure, h the total heat above 32° of the feed water, and 970.4 the heat of vaporization, or latent heat, of steam at 212° F. The values of these total heats and of the latent heat are those given in Marks and Davis's Steam Tables.

The factors are given for every 3° of feed-water temperature between 32° and 212°, and for every 5 or 10 lbs. steam pressure within the ordinary working limits of pressure. Intermediate values correct to the third decimal place may easily be found by interpolation.

The figures given apply only to saturated steam. For superheated steam, factors of evaporation must be calculated by the formula, taking H as the total heat of superheated steam as found in the table of properties of superheated steam.

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM.

Lbs. Gage press. / Abs. press.	0.3 / 15	10.3 / 25	20.3 / 35	30.3 / 45	40.3 / 55	50.3 / 65	60.3 / 75	70.3 / 85	80.3 / 95	85.3 / 100
Feed Water.	Factors of Evaporation.									
212°F.	1.0003	1.0103	1.0169	1.0218	1.0258	1.0290	1.0316	1.0340	1.0361	1.0370
209	34	34	1.0200	50	89	1.0321	47	71	92	1.0401
206	65	65	31	81	1.0320	52	79	1.0402	1.0423	32
203	96	96	62	1.0312	51	83	1.0410	33	54	63
200	1.0127	1.0227	93	43	82	1.0414	41	64	85	94
197	58	58	1.0324	74	1.0413	45	72	95	1.0516	1.0525
194	89	89	55	1.0405	44	76	1.0503	1.0526	47	56
191	1.0220	1.0320	86	36	75	1.0507	34	57	78	87
188	51	51	1.0417	67	1.0506	38	65	88	1.0609	1.0618
185	82	82	48	98	37	69	96	1.0619	40	49
182	1.0313	1.0413	79	1.0529	68	1.0600	1.0627	50	71	80
179	44	44	1.0510	60	99	31	58	81	1.0702	1.0711
176	75	75	41	91	1.0630	62	89	1.0712	33	42
173	1.0406	1.0506	72	1.0622	61	93	1.0720	43	64	73
170	37	37	1.0603	53	92	1.0724	51	74	95	1.0804
167	68	68	34	84	1.0723	55	82	1.0805	1.0826	35
164	99	99	65	1.0715	54	86	1.0812	36	57	66
161	1.0530	1.0630	96	85	85	1.0817	43	67	88	97
158	61	61	1.0727	76	1.0816	47	74	98	1.0919	1.0928
155	92	92	58	1.0807	46	78	1.0905	1.0929	50	59
152	1.0623	1.0723	89	38	77	1.0909	36	60	80	90
149	54	54	1.0820	69	1.0908	40	67	91	1.1011	1.1021
146	85	85	51	1.0900	39	71	98	1.1022	42	52
143	1.0715	1.0815	81	31	70	1.1002	1.1029	52	73	82
140	46	46	1.0912	62	1.1001	33	60	83	1.1104	1.1113
137	77	77	43	93	32	64	91	1.1114	35	44
134	1.0808	1.0908	74	1.1023	63	95	1.1121	45	66	75
131	39	39	1.1005	54	93	1.1125	52	76	97	1.1206
128	70	70	36	85	1.1124	56	83	1.1207	1.1227	37
125	1.0901	1.1001	67	1.1116	55	87	1.1214	38	58	68
122	31	31	97	47	86	1.1218	45	69	89	98
119	62	62	1.1128	78	1.1217	49	76	99	1.1320	1.1329
116	93	93	59	1.1209	48	80	1.1306	1.1330	51	60
113	1.1024	1.1124	90	39	79	1.1310	37	61	82	91
110	55	55	1.1221	70	1.1309	41	68	92	1.1412	1.1422
107	86	86	52	1.1301	40	72	99	1.1423	43	53
104	1.1116	1.1216	82	32	71	1.1403	1.1430	53	74	83
101	47	47	1.1313	63	1.1402	34	61	84	1.1505	1.1514
98	78	78	44	93	33	65	91	1.1515	36	45
95	1.1209	1.1309	75	1.1424	63	95	1.1522	46	66	76
92	40	40	1.1406	55	94	1.1526	53	77	97	1.1607
89	71	71	37	86	1.1525	57	84	1.1608	1.1628	37
86	1.1301	1.1401	67	1.1518	56	88	1.1615	38	59	68
83	32	32	98	48	87	1.1619	46	69	90	99
80	63	63	1.1529	78	1.1618	50	76	1.1700	1.1721	1.1730
77	94	94	60	1.1609	48	80	1.1707	31	51	61
74	1.1425	1.1525	91	40	79	1.1711	38	62	82	92
71	55	55	1 1621	71	1.1710	42	69	92	1.1813	1.1822
68	86	86	52	1.1702	41	73	1.1800	1.1823	44	53
65	1.1517	1.1617	83	33	72	1.1804	30	54	75	84
62	48	48	1.1714	63	1.1803	35	61	85	1.1906	1.1915
59	79	79	45	94	33	65	92	1.1916	37	46
56	1.1610	1.1710	76	1.1825	64	96	1.1923	47	67	77
53	41	41	1.1807	56	95	1.1927	54	78	98	1.2008
50	72	72	38	87	1.1926	58	85	1.2009	1.2029	39
47	1.1703	1.1803	69	1.1918	57	89	1.2016	40	60	70
44	34	34	1.1900	49	88	1.2020	47	71	91	1.2101
41	65	65	31	80	1.2019	51	78	1.2102	1.2122	32
38	96	96	62	1.2011	50	82	1.2109	33	53	63
35	1.1827	1.1927	93	42	81	1.2113	40	64	84	94
32	58	58	1.2024	73	1.2113	44	71	95	1.2216	1.2225

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM.—*Continued.*

Gage press. Lbs.	90.3	95.3	100.3	105.3	110.3	115.3	120.3	125.3	130.3	135.3	140.3
Abs. press.	105	110	115	120	125	130	135	140	145	150	155
Feed Water.	Factors of Evaporation.										
212° F.	1.0379	1.0387	1.0396	1.0404	1.0411	1.0418	1.0425	1.0431	1.0437	1.0443	1.0449
209	1.0410	1.0419	1.0427	35	42	49	56	62	68	74	80
206	41	50	58	66	73	81	87	93	99	1.0505	1.0511
203	72	81	89	97	1.0504	1.0512	1.0518	1.0524	1.0530	36	43
200	1.0504	1.0512	1.0520	1.0528	35	43	49	55	61	67	74
197	35	43	51	59	66	74	80	86	92	98	1.0605
194	66	74	82	90	97	1.0605	1.0611	1.0617	1.0623	1.0629	36
191	97	1.0605	1.0613	1.0621	1.0629	36	42	48	54	60	67
188	1.0628	36	44	52	60	67	73	79	85	91	98
185	59	67	75	83	91	98	1.0704	1.0710	1.0716	1.0722	1.0729
182	90	98	1.0706	1.0714	1.0721	1.0729	35	41	47	53	60
179	1.0721	1.0729	37	45	52	60	66	72	78	84	91
176	52	60	68	76	83	91	97	1.0803	1.0809	1.0815	1.0822
173	82	91	99	1.0807	1.0814	1.0822	1.0828	34	40	46	53
170	1.0813	1.0822	1.0830	38	45	53	59	65	71	77	83
167	44	53	61	69	76	84	90	96	1.0902	1.0908	1.0914
164	75	84	92	1.0900	1.0907	1.0914	1.0921	1.0927	33	39	45
161	1.0906	1.0914	1.0923	31	38	45	52	58	64	70	76
158	37	45	54	62	69	76	82	89	95	1.1001	1.1007
155	68	76	85	93	1.1000	1.1007	1.1013	1.1020	1.1026	32	38
152	99	1.1007	1.1015	1.1024	31	38	44	51	57	63	69
149	1.1030	38	46	55	62	69	75	81	88	94	1.1100
146	61	69	77	86	93	1.1100	1.1106	1.1112	1.1119	1.1125	31
143	92	1.1100	1.1108	1.1116	1.1124	31	37	43	49	56	62
140	1.1123	31	39	47	54	62	68	74	80	86	93
137	53	62	70	78	85	93	99	1.1205	1.1211	1.1217	1.1224
134	84	93	1.1201	1.1209	1.1216	1.1223	1.1230	36	42	48	54
131	1.1215	1.1223	32	40	47	54	60	67	73	79	85
128	46	54	62	71	78	85	91	98	1.1304	1.1310	1.1316
125	77	85	93	1.1302	1.1309	1.1316	1.1322	1.1328	35	41	47
122	1.1308	1.1316	1.1324	32	40	47	53	59	65	71	78
119	39	47	55	63	70	78	84	90	96	1.1402	1.1409
116	69	78	86	94	1.1401	1.1408	1.1415	1.1421	1.1427	33	39
113	1.1400	1.1408	1.1417	1.1425	32	39	45	52	58	64	70
110	31	39	47	56	63	70	76	82	89	95	1.1501
107	62	70	78	87	94	1.1501	1.1507	1.1513	1.1519	1.1526	32
104	92	1.1501	1.1509	1.1517	1.1525	32	38	44	50	56	63
101	1.1523	32	40	48	55	63	69	75	81	87	93
98	54	62	71	79	86	93	1.1600	1.1606	1.1612	1.1618	1.1624
95	85	93	1.1602	1.1610	1.1617	1.1624	30	37	43	49	55
92	1.1616	1.1624	32	41	48	55	61	67	74	80	86
89	47	55	63	71	79	86	92	98	1.1704	1.1711	1.1717
86	78	86	94	1.1702	1.1710	1.1717	1.1723	1.1729	35	41	48
83	1.1708	1.1717	1.1725	33	40	48	54	60	66	72	78
80	39	47	56	64	71	78	85	91	97	1.1803	1.1809
77	70	78	86	95	1.1802	1.1809	1.1815	1.1822	1.1828	34	40
74	1.1801	1.1809	1.1817	1.1826	33	40	46	52	59	65	71
71	32	40	48	56	64	71	77	83	89	96	1.1902
68	62	71	79	87	94	1.1902	1.1908	1.1914	1.1920	1.1926	33
65	93	1.1902	1.1910	1.1918	1.1925	33	39	45	51	57	68
62	1.1924	32	41	49	56	63	70	76	82	88	94
59	55	63	72	80	87	94	1.2000	1.2007	1.2013	1.2019	1.2025
56	86	94	1.2002	1.2011	1.2018	1.2025	1 31	38	44	50	56
53	1.2017	1.2025	33	42	49	56	62	68	75	81	87
50	48	56	64	73	80	87	93	99	1.2106	1.2112	1.2118
47	79	87	95	1.2104	1.2111	1.2118	1.2124	1.2130	37	43	49
44	1.2110	1.2118	1.2126	35	42	49	55	61	68	74	80
41	41	49	57	66	73	80	86	92	99	1.2205	1.2211
38	72	80	88	97	1.2204	1.2211	1.2217	1.2223	1.2230	36	42
35	1.2203	1.2211	1.2219	1.2228	35	42	48	55	61	67	73
32	34	42	51	59	66	73	79	86	92	98	1.2340

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM.—*Continued.*

Lbs. Gage press. / Abs. press.	145.3 / 160	150.3 / 165	155.3 / 170	160.3 / 175	165.3 / 180	170.3 / 185	175.3 / 190	180.3 / 195	185.3 / 200	190.3 / 205	195.3 / 210
Feed Water.	Factors of Evaporation.										
212° F.	1.0455	1.0460	1.0464	1.0469	1.0474	1.0478	1.0483	1.0487	1.0492	1.0496	1.0499
209	86	91	95	1.0500	1.0505	1.0509	1.0514	1.0519	1.0523	1.0527	1.0530
206	1.0517	1.0522	1.0526	31	36	40	45	50	54	58	61
203	48	53	57	62	67	71	77	81	85	89	92
200	79	84	88	93	98	1.0602	1.0608	1.0612	1.0616	1.0620	1.0623
197	1.0610	1.0615	1.0619	1.0624	1.0629	33	39	43	47	51	54
194	41	46	50	55	60	64	70	74	78	82	85
191	72	77	81	86	91	95	1.0701	1.0705	1.0709	1.0713	1.0716
188	1.0703	1.0708	1.0712	1.0717	1.0722	1.0727	32	36	40	44	47
185	34	39	43	48	53	58	63	67	71	75	78
182	65	70	74	79	84	88	94	98	1.0802	1.0806	1.0809
179	96	1.0801	1.0805	1.0810	1.0815	1.0819	1.0825	1.0829	33	37	40
176	1.0827	32	36	41	46	50	56	60	64	68	71
173	58	63	67	72	77	81	87	91	95	99	1.0902
170	89	94	98	1.0903	1.0908	1.0912	1.0917	1.0922	1.0926	1.0930	33
167	1.0920	1.0925	1.0929	34	39	43	48	53	57	61	64
164	51	56	60	65	70	74	79	84	88	92	95
161	81	87	91	96	1.1001	1.1005	1.1010	1.1014	1.1019	1.1023	1.1026
158	1.1012	1.1018	1.1022	1.1027	32	36	41	45	49	54	57
155	43	48	53	58	63	67	72	76	80	85	88
152	74	79	83	89	94	98	1.1103	1.1107	1.1111	1.1115	1.1119
149	1.1105	1.1110	1.1114	1.1120	1.1125	1.1129	34	38	42	46	49
146	36	41	45	50	56	60	65	69	73	77	80
143	67	72	76	81	86	91	96	1.1200	1.1204	1.1208	1.1211
140	98	1.1203	1.1207	1.1212	1.1217	1.1221	1.1227	31	35	39	42
137	1.1229	34	38	43	48	52	58	62	66	70	73
134	59	65	69	74	79	83	88	92	97	1.1301	1.1304
131	90	95	1.1300	1.1305	1.1310	1.1314	1.1319	1.1323	1.1327	32	35
128	1.1321	1.1326	30	36	41	45	50	54	58	62	66
125	52	57	61	66	72	76	81	85	89	93	96
122	83	88	92	97	1.1402	1.1407	1.1412	1.1416	1.1420	1.1424	1.1428
119	1.1414	1.1419	1.1423	1.1428	33	37	43	47	51	55	57
116	45	50	54	59	61	68	73	78	82	86	89
113	75	81	85	90	95	99	1.1504	1.1508	1.1512	1.1515	1.1520
110	1.1506	1.1511	1.1515	1.1521	1.1526	1.1530	35	39	43	47	50
107	37	42	46	51	57	61	66	70	74	78	81
104	68	73	77	82	87	92	97	1.1601	1.1605	1.1609	1.1612
101	99	1.1604	1.1608	1.1613	1.1618	1.1622	1.1627	32	36	40	43
98	1.1629	35	39	44	49	53	58	62	67	71	74
95	60	65	70	75	80	84	89	93	97	1.1701	1.1705
92	91	96	1.1700	1.1705	1.1711	1.1715	1.1720	1.1724	1.1728	32	35
89	1.1722	1.1727	31	36	42	46	51	55	59	63	66
86	53	58	62	67	72	76	82	86	90	94	97
83	84	89	93	98	1.1803	1.1807	1.1812	1.1817	1.1821	1.1825	1.1828
80	1.1814	1.1820	1.1824	1.1829	34	38	43	47	52	56	59
77	45	50	54	60	65	69	74	78	82	86	90
74	76	81	85	90	96	1.1900	1.1905	1.1909	1.1913	1.1917	1.1920
71	1.1907	1.1912	1.1916	1.1921	1.1926	31	36	40	44	48	51
68	38	43	47	52	57	61	67	71	75	79	82
65	69	74	78	83	88	92	97	1.2002	1.2006	1.2010	1.2013
62	99	1.2005	1.2009	1.2014	1.2019	1.2023	1.2028	32	36	41	44
59	1.2030	35	40	45	50	54	59	63	67	72	75
56	61	66	70	76	81	85	90	94	98	1.2102	1.2106
53	92	97	1.2101	1.2107	1.2112	1.2116	1.2121	1.2125	1.2129	33	36
50	1.2123	1.2128	32	37	43	47	52	56	60	64	67
47	54	59	63	68	74	78	83	87	91	95	98
44	85	90	94	1.2200	1.2205	1.2209	1.2214	1.2218	1.2222	1.2226	1.2229
41	1.2216	1.2221	1.2225	31	36	40	45	49	53	57	60
38	47	52	56	62	67	71	76	80	84	88	91
35	78	83	88	93	98	1.2302	1.2307	1.2311	1.2315	1.2320	1.2323
32	1.2309	1.2315	1.2319	1.2324	1.2329	33	38	42	46	51	54

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM.—*Continued.*

Lbs. Gage press. / Abs. press.	200.3 / 215	205.3 / 220	210.3 / 225	215.3 / 230	220.3 / 235	225.3 / 240	230.3 / 245	235.3 / 250	240.3 / 255	245.3 / 260	250.3 / 265
Feed Water.	Factors of Evaporation.										
212° F.	1.0503	1.0507	1.0510	1.0513	1.0517	1.0520	1.0523	1.0527	1.0529	1.0533	1.0535
209	34	38	41	44	48	52	55	58	60	64	66
206	65	69	72	75	79	83	86	89	91	95	97
203	96	1.0600	1.0603	1.0606	1.0611	1.0614	1.0617	1.0620	1.0622	1.0626	1.0629
200	1.0627	31	34	37	42	45	48	51	53	57	60
197	58	62	65	68	73	76	79	82	84	88	91
194	89	93	96	1.0700	1.0704	1.0707	1.0710	1.0713	1.0715	1.0719	1.0722
191	1.0720	1.0724	1.0727	31	35	38	41	44	46	50	53
188	51	55	58	62	66	69	72	75	78	81	84
185	82	86	89	93	97	1.0800	1.0830	1.0806	1.0809	1.0812	1.0816
182	1.0813	1.0817	1.0820	1.0823	1.0828	31	34	37	39	43	45
179	44	48	51	54	59	62	65	68	70	74	77
176	75	79	82	86	90	93	96	99	1.0901	1.0905	1.0908
173	1.0906	1.0910	1.0913	1.0916	1.0921	1.0924	1.0927	1.0930	32	36	39
170	37	41	44	47	51	55	58	61	63	67	69
167	68	72	75	78	82	86	89	92	94	98	1.1001
164	99	1.1003	1.1006	1.1009	1.1013	1.1016	1.1019	1.1023	1.1025	1.1029	31
161	1.1030	34	37	40	44	47	50	54	56	60	62
158	61	65	68	71	75	78	81	85	87	91	93
155	92	96	99	1.1102	1.1106	1.1109	1.1112	1.1115	1.1118	1.1122	1.1124
152	1.1123	1.1127	1.1130	33	37	40	43	46	49	53	55
149	54	58	61	64	68	71	74	77	80	83	86
146	84	89	92	95	99	1.1202	1.1205	1.1208	1.1211	1.1214	1.1217
143	1.1215	1.1219	1.1223	1.1226	1.1230	33	36	39	42	45	48
140	46	50	53	56	61	64	67	70	72	76	79
137	77	81	84	87	92	95	98	1.1301	1.1303	1.1307	1.1310
134	1.1308	1.1312	1.1315	1.1318	1.1322	1.1326	1.1329	32	34	38	40
131	39	43	46	49	53	56	59	62	65	69	71
128	70	74	77	80	84	87	90	93	96	1.1400	1.1402
125	1.1400	1.1405	1.1408	1.1411	1.1415	1.1418	1.1421	1.1424	1.1427	30	33
122	31	35	39	42	46	49	52	55	58	61	64
119	62	66	69	72	77	80	83	86	88	92	95
116	93	97	1.1500	1.1503	1.1507	1.1511	1.1514	1.1517	1.1519	1.1523	1.1525
113	1.1524	1.1528	31	34	38	41	44	48	50	54	56
110	55	59	62	65	69	72	75	78	81	85	87
107	85	90	93	96	1.1600	1.1603	1.1606	1.1609	1.1612	1.1615	1.1618
104	1.1616	1.1620	1.1624	1.1627	31	34	37	40	43	46	49
101	47	51	54	57	61	65	68	71	73	77	80
98	78	82	85	88	92	95	98	1.1702	1.1704	1.1708	1.1710
95	1.1709	1.1713	1.1716	1.1719	1.1723	1.1726	1.1729	32	35	39	41
92	39	44	47	50	54	57	60	63	66	69	72
89	70	75	78	81	85	88	91	94	97	1.1800	1.1803
86	1.1801	1.1805	1.1808	1.1812	1.1816	1.1819	1.1822	1.1825	1.1827	31	34
83	32	36	39	42	46	50	53	56	58	62	64
80	63	67	70	73	77	80	83	87	89	93	95
77	94	98	1.1901	1.1904	1.1908	1.1911	1.1914	1.1917	1.1920	1.1924	1.1926
74	1.1924	1.1929	32	35	39	42	45	48	51	54	57
71	55	59	63	66	70	73	76	79	82	85	88
68	86	90	93	96	1.2001	1.2004	1.2007	1.2010	1.2012	1.2016	1.2019
65	1.2017	1.2021	1.2024	1.2027	31	35	38	41	43	47	49
62	48	52	55	58	62	65	68	72	74	78	80
59	79	83	86	89	93	96	99	1.2102	1.2105	1.2109	1.2111
56	1.2110	1.2114	1.2117	1.2120	1.2124	1.2127	1.2130	33	36	40	42
53	41	45	48	51	55	58	61	64	67	70	73
50	71	76	79	82	86	89	92	95	98	1.2201	1.2204
47	1.2202	1.2207	1.2210	1.2213	1.2217	1.2220	1.2223	1.2226	1.2229	32	35
44	34	38	41	44	48	51	54	57	60	63	66
41	65	69	72	75	79	82	85	88	91	94	97
38	96	1.2300	1.2303	1.2306	1.2310	1.2313	1.2316	1.2319	1.2322	1.2325	1.2328
35	1.2327	31	34	37	41	44	47	50	53	57	59
32	58	62	65	68	72	75	78	82	84	88	90

Chimney-draft Theory.—The commonly accepted theory of chimney-draft, based on Peclet's and Rankine's hypotheses (see Rankine's Steam-engine), is discussed by Prof. De Volson Wood in Trans. A. S. M. E., vol. xi.

Peclet represented the law of draft by the formula

$$h = \frac{u^2}{2g}\left(1 + G + \frac{fl}{m}\right),$$

in which h is the "head," defined as such a height of hot gases as, if added to the column of gases in the chimney, would produce the same pressure at the furnace as a column of outside air, of the same area of base, and a height equal to that of the chimney;

u is the required velocity of gases in the chimney;

G a constant to represent the resistance to the passage of air through the coal;

l the length of the flues and chimney;

m the mean hydraulic depth, or the area of a cross-section divided by the perimeter;

f a constant depending upon the nature of the surfaces over which the gases pass, whether smooth, or sooty and rough.

Rankine's formula (Steam-engine, p. 288), derived by giving certain values to the constants (so-called) in Peclet's formula, is

$$h = \frac{\frac{\tau_0}{\tau_2}(0.0807)}{\frac{\tau_0}{\tau_1}(0.084)}H - H = \left(0.96\frac{\tau_1}{\tau_2} - 1\right)H;$$

in which H = the height of the chimney in feet;

τ_0 = 493° F., absolute (temperature of melting ice);

τ_1 = absolute temperature of the gases in the chimney;

τ_2 = absolute temperature of the external air.

Prof. Wood derives from this a still more complex formula which gives the height of chimney required for burning a given quantity of coal per second, and from it he calculates the following table, showing the height of chimney required to burn respectively 24, 20, and 16 lbs. of coal per sq. ft. of grate per hour, for the several temperatures of the chimney-gases given.

Rankine's formula gives a maximum draft when $\tau = 21/12\tau_2$, or 622° F., when the outside temperature is 60°. Prof. Wood says:

"This result is not a fixed value, but departures from theory in practice do not affect the result largely. There is, then, in a properly constructed chimney, properly working, a temperature giving a maximum draft,* and that temperature is not far from the value given by Rankine, although in special cases it may be 50° or 75° more or less."

Outside Air, τ_2	Chimney-gas.		Coal per Square Foot of Grate per Hour, lbs.		
	τ_1 Absolute.	Temperature, Fahrenheit.	24	20	16
			Height H, Feet.		
520° Absolute, or 59° F.	700	239	250.9	157.6	67.8
	800	339	172.4	115.8	55.7
	1000	539	149.1	100.0	48.7
	1100	639	148.8	98.9	48.2
	1200	739	152.0	100.9	49.1
	1400	939	159.9	105.7	51.2
	1600	1139	168.8	111.0	53.5
	2000	1539	206.5	132.2	63.0

All attempts to base a practical formula for chimneys upon the theoretical formulæ of Peclet and Rankine have failed on account of the impossibility of assigning correct values to the so-called "constants" G and f. (See Trans. A. S. M. E., xi. 984.)

Force or Intensity of Draft.—The force of the draft is equal to the difference between the weight of the column of hot gases inside of the chimney and the weight of a column of the external air of the same height. It is measured by a draft-gage, usually a U-tube partly filled with water, one leg connected by a pipe to the interior of the flue, and the other open to the external air.

If D is the density of the air outside, d the density of the hot gas inside, in lbs. per cu. ft., h the height of the chimney in feet, and 0.192 the factor for converting pressure in lbs. per sq. ft. into inches of water-column, then the formula for the force of draft expressed in inches of water is,

$$F = 0.192h(D - d).$$

* Much confusion to students of the theory of chimneys has resulted from their understanding the words maximum draft to mean maximum intensity or pressure of draft, as measured by a draft-gage. It here means maximum quantity or weight of gases passed up the chimney. The maximum intensity is found only with maximum temperature, but after the temperature reaches about 622° F. the density of the gas decreases more rapidly than its velocity increases, so that the weight is a maximum about 622° F., as shown by Rankine.

The density varies with the absolute temperature (see Rankine).

$$d = \frac{\tau_0}{\tau_1}0.084; \quad D = 0.0807\frac{\tau_0}{\tau_2},$$

where τ_0 is the absolute temperature at 32° F., = 493, τ_1 the absolute temperature of the chimney-gases, and τ_2 that of the external air. Substituting these values the formula for force of draft becomes

$$F = 0.192h\left(\frac{39.79}{\tau_2} - \frac{41.41}{\tau_1}\right) = h\left(\frac{7.64}{\tau_2} - \frac{7.95}{\tau_1}\right).$$

To find the maximum intensity of draft for any given chimney, the heated column being 600° F., and the external air 60°, multiply the height above grate in feet by .0073, and the product is the draft in inches of water.

HEIGHT OF WATER COLUMN DUE TO UNBALANCED PRESSURE IN CHIMNEY 100 FEET HIGH. (*The Locomotive*, 1884.)

Temp. in the Chimney.	Temperature of the External Air—Barometer, 14.7 lbs. per Square Inch.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
220	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
240	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
260	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
280	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
300	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
320	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
340	.662	.638	.593	.563	.530	.501	.472	.443	.419	.392	.367
360	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
380	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
400	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
420	.754	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
440	.773	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
460	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
480	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
500	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

For any other height of chimney than 100 ft. the height of water-column is found by simple proportion, the height of water-column being directly proportional to the height of chimney.

The calculations have been made for a chimney 100 ft. high, with various temperatures outside and inside of the flue, and on the supposition that the temperature of the chimney is uniform from top to bottom. This is the basis on which all calculations respecting the draft-power of chimneys have been made by Rankine and other writers,

but it is very far from the truth in most cases. The difference will be shown by comparing the reading of the draft-gage with the table given. In one case a chimney 122 ft. high showed a temperature at the base of 320°, and at the top of 230°.

Box, in his "Treatise on Heat," gives the following table:

DRAFT POWERS OF CHIMNEYS, ETC., WITH THE INTERNAL AIR AT 552° AND THE EXTERNAL AIR AT 62°, AND WITH THE DAMPER NEARLY CLOSED.

Height of Chimney in Feet.	Draft Power in Ins. of Water.	Theoretical Velocity, in Feet per Second.		Height of Chimney in Feet.	Draft Power in Ins. of Water.	Theoretical Velocity, in Feet per Second.	
		Cold Air Entering.	Hot Air at Exit.			Cold Air Entering.	Hot Air at Exit.
10	.073	17.8	35.6	80	.585	50.6	101.2
20	.146	25.3	50.6	90	.657	53.7	107.4
30	.219	31.0	62.0	100	.730	56.5	113.0
40	.292	35.7	71.4	120	.876	62.0	124.0
50	.365	40.0	80.0	150	1.095	69.3	138.6
60	.438	43.8	87.6	175	1.277	74.3	149.6
70	.511	47.3	94.6	200	1.460	80.0	160.0

Rate of Combustion Due to Height of Chimney.—Trowbridge's "Heat and Heat-engines" gives the following table showing the heights of chimney for producing certain rates of combustion per sq. ft. of section of the chimney. It may be approximately true for anthracite in moderate and large sizes, but greater heights than are given in the table are needed to secure the given rates of combustion with small sizes of anthracite, and for bituminous coal smaller heights will suffice if the coal is reasonably free from ash—5 per cent or less.

Heights in Feet.	Lbs. of Coal Burned per Hour per Square Foot of Section of Chimney.	Lbs. of Coal Burned per Square Foot of Grate, the Ratio of Grate to Section of Chimney being 8 to 1.	Heights in Feet.	Lbs. of Coal Burned per Hour per Square Foot of Section of Chimney.	Lbs. of Coal Burned per Square Foot of Grate, the Ratio of Grate to Section of Chimney being 8 to 1.
20	60	7.5	70	126	15.8
25	68	8.5	75.	131	16.4
30	76	9.5	80	135	16.9
35	84	10.5	85	139	17.4
40	93	11.6	90	144	18.0
45	99	12.4	95	148	18.5
50	105	13.1	100	152	19.0
55	111	13.8	105	156	19.5
60	116	14.5	110	160	20.0
65	121	15.1			

Thurston's rule for rate of combustion effected by a given height of chimney (Trans. A. S. M. E., xi. 991) is: Subtract 1 from twice the square root of the height and the result is the rate of combustion

in pounds per square foot of grate per hour, for anthracite. Or rate $= 2\sqrt{h} - 1$, in which h is the height in feet. This rule gives the following:

$h =$	50	60	70	80	90	100	110	125	150	175	200
$2\sqrt{h}-1 =$	13.14	14.49	15.73	16.89	17.97	19	19.97	21.36	23.49	25.45	27.28

The results agree closely with Trowbridge's table given above. In practice the high rates of combustion for high chimneys given by the formula are not generally obtained, for the reason that with high chimneys there are usually long horizontal flues serving many boilers, and the friction and the interference of currents from the several boilers are apt to cause the intensity of draft in the branch flues leading to each boiler to be much less than that at the base of the chimney. The draft of each boiler is also usually restricted by a damper and by bends in the gas-passages. In a battery of several boilers connected to a chimney 150 ft. high, the author found a draft of ¾-in. water-column at the boiler nearest the chimney, and only ¼-in. at the boiler farthest away. The first boiler was wasting fuel from too high temperature of the chimney-gases, 900°, having too large a grate-surface for the draft, and the last boiler was working below its rated capacity and with poor economy, on account of insufficient draft.

The effect of changing the length of the flue leading into a chimney 60 ft. high and 2 ft. 9 ins. square is given in the following table, from Box on "Heat":

Length of Flue in Feet.	Horse-power.	Length of Flue in Feet.	Horse-power.
50	107.6	800	56.1
100	100.0	1000	51.4
200	85.3	1500	43.3
400	70.8	2000	38.2
600	62.5	3000	31.7

The temperature of the gases in this chimney was assumed to be 552° F., and that of the atmosphere 62°.

Height of Chimney Required for Different Fuels.—The minimum height necessary varies with the fuel, wood requiring the least, then good bituminous coal, and fine sizes of anthracite the greatest. It also varies with the character of the boiler—the smaller and more circuitous the gas-passages the higher the stack required; also with the number of boilers, a single boiler requiring less height than several that discharge into a horizontal flue. No general rule can be given.

C. L. Hubbard (*Am. Electrician,* Mar., 1904) says: The following heights have been found to give good results in plants of moderate size, and to produce sufficient draught to force the boilers from 20 to 30 per cent above their rating:

With free-burning bituminous coal, 75 feet; with anthracite of medium and large size, 100 feet; with slow-burning bituminous coal, 120 feet; with anthracite pea coal, 130 feet; with anthracite buckwheat coal, 150 feet. For plants of 700 or 800 horse-power and over, the chimney should not be less than 150 feet high regardless of the kind of coal to be used.

Temperatures at Different Heights in Chimneys.—Peabody and Miller (Steam Boilers, page 199) give the chart which is herewith reproduced (Fig. 278) showing the temperatures that were found at different heights in three chimneys. A was an unlined steel stack, 3 ft. diam., 100 ft. high. B was a brick stack 3 ft. square, 102 ft. high. C and D are the same stack, a 250-ft. Custodis radial brick, 18 ft. internal diameter at bottom and 16 ft. at top. The temperature of the gas entering the stack was much higher in the series of tests shown by curve C than in those shown by curve D. The curve A, of the steel stack, shows a much more rapid diminution of temperature than the curves of either of the brick stacks. In these tests the draft at the base of the chimney was measured and compared with the calculated draft, and the greatest variation found was 0.09 in.

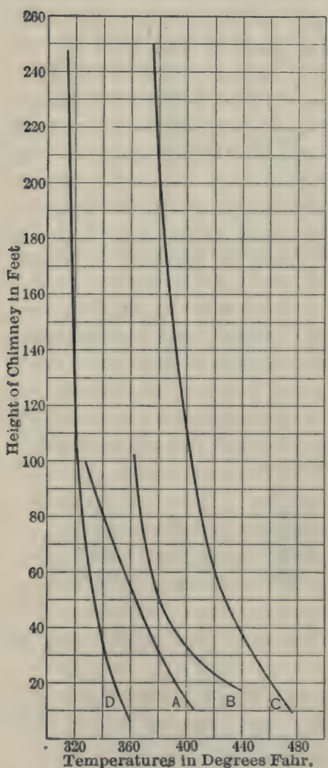


FIG. 278.—TEMPERATURES AT DIFFERENT HEIGHTS OF CHIMNEY.

Peabody and Miller give the following formula for curve C: $HT^n = K$, in which H is any height above the middle of the flue; $T =$ temperature °F. + 460; $\log K = 75.4$ and $n = 25$. It is evident that this formula applies only to the particular conditions under which the chimney was tested, for curve D, for the same chimney, gives approximately $\log K = 143$ and $n = 48.7$.

The average temperature in the 250-ft. chimney according to the curve C is about 400°, with 70° F. outside temperature the theoretical draft, according to the table on page 673 is 1.28 in. If the average

temperature was the same as the initial temperature the draft would be 1.48 in.

High Chimneys not Necessary.—Chimneys above 150 ft. in height are very costly, and their increased cost is rarely justified by increased efficiency. In recent practice it has become somewhat common to build two or more smaller chimneys instead of one large one. A notable example is the Spreckles Sugar Refinery in Philadelphia, where three separate chimneys are used for one boiler-plant of 7500 H.P. The three chimneys are said to have cost several thousand dollars less than a single chimney of their combined capacity would have cost. Very tall chimneys have been characterized by one writer as "monuments to the folly of their builders."

Size of Chimneys corresponding to Given Capacity of Boilers.—The formula given below, and the table calculated therefrom for chimneys up to 96 ins. diameter and 200 ft. high were first published by the author in 1884 (Trans. A. S. M. E., vi. 81). They have met with much approval since that date by engineers who have used them, and have been frequently published in boiler-makers' catalogues and elsewhere. The table is now extended to cover chimneys up to 12 ft. diameter and 300 ft. high. The sizes corresponding to the given commercial horse-powers are believed to be ample for all cases in which the draft areas through the boiler-flues and connections are sufficient, say not less than 20 per cent greater than the area of the chimney, and in which the draft between the boilers and chimney is not checked by long horizontal passages and right-angled bends.

Note that the figures in the table correspond to a coal consumption of 5 lbs. of coal per horse-power per hour. This liberal allowance is made to cover the contingencies of poor coal being used, and of the boilers being driven beyond their rated capacity. In large plants with economical boilers and engines, good fuel and other favorable conditions, which will reduce the maximum rate of coal consumption at any one time to less than 5 lbs. per H.P. per hour, the figures in the table may be multiplied by the ratio of 5 to the maximum expected coal consumption per H.P. per hour. Thus, with conditions which make the maximum coal consumption only 2.5 lbs. per hour, the chimney 300 ft. high $\times$ 12 ft. diameter should be sufficient for $6155 \times 2 =$ 12,310 horse-power. The formula is based on the following data:

1. The draft-power of the chimney varies as the square root of the height.

2. The retarding of the ascending gases by friction may be considered as equivalent to a diminution of the area of the chimney, or to a lining of the chimney by a layer of gas which has no velocity. The thickness of this lining is assumed to be 2 ins. for all chimneys, or the diminution of area equal to the perimeter $\times$ 2 ins. (neglecting the overlapping of the corners of the lining). Let $D =$ diameter in feet, $A =$ area, and $E =$ effective area in square feet.

For square chimneys, $E = D^2 - \frac{8D}{12} = A - \frac{2}{3}\sqrt{A}$.

For round chimneys, $E = \frac{\pi}{4}\left(D^2 - \frac{8D}{12}\right) = A - 0.591\sqrt{A}$.

For simplifying calculations, the coefficient of $\sqrt{A}$ may be taken as 0.6 for both square and round chimneys, and the formula becomes

$$E = A - 0.6\sqrt{A}.$$

3. The power varies directly as this effective area E.

4. A chimney should be proportioned so as to be capable of giving sufficient draft to cause the boiler to develop much more than its rated power, in case of emergencies, or to cause the combustion of 5 lbs. of fuel per rated horse-power of boiler per hour.

5. The power of the chimney varying directly as the effective area, E, and as the square root of the height, H, the formula for horse-power of boiler for a given size of chimney will take the form H.P. $= CE\sqrt{H}$, in which C is a constant, the average value of which, obtained by plotting the results obtained from numerous examples in practice, the author finds to be 3.33.

The formula for horse-power then is

$$\text{H.P.} = 3.33E\sqrt{H}, \quad \text{or} \quad \text{H.P.} = 3.33(A - 0.6\sqrt{A})\sqrt{H}.$$

Pounds of coal per hour $= 16.65\ (A - 0.6\sqrt{A})\sqrt{H}$.

If the horse-power of boiler is given, to find the size of chimney, the height being assumed,

$$E = \frac{0.3\ \text{H.P.}}{\sqrt{H}} = A - 0.6\sqrt{A}.$$

For round chimneys, diameter of chimney = diam. of $E + 4$ ins.

For square chimneys, side of chimney $= \sqrt{E} + 4$ ins.

If effective area E is taken in square feet, the diameter in inches is $d = 13.54\sqrt{E} + 4$ ins., and the side of a square chimney in inches is $s = 12\sqrt{E} + 4$ ins.

If horse-power is given and area assumed, the height $H = \left(\frac{0.3\ \text{H.P.}}{E}\right)^2$.

In proportioning chimneys the height is generally first assumed, with due consideration to the heights of surrounding buildings or hills near to the proposed chimney, the length of horizontal flues, the character of coal to be used, etc., and then the diameter required for

SIZE OF CHIMNEYS FOR STEAM-BOILERS.

Formula, H. P. = $3.33(A - 0.6\sqrt{A})\sqrt{H}$. Assuming 1 H. P. = 5 lbs. of coal burned per hour.)

Diam. Inches.	Area A. sq. ft.	Effective Area. $E = A - 0.6\sqrt{A}$ Square Feet.	Height of Chimney.														Equivalent. Square Chimney. Side of Square. $\sqrt{E} + 4$ ins.
			50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	225 ft.	250 ft.	300 ft.	
			Commercial Horse-power of Boiler.														
18	1.77	.97	23	25	27	29	....	....	....	....	....	....	....	....	....	....	16
21	2.41	1.47	35	38	41	44	....	....	....	....	....	....	....	....	....	....	19
24	3.14	2.08	49	.54	58	62	66	....	....	....	....	....	....	....	....	....	22
27	3.98	2.78	65	72	78	83	88	....	....	....	....	....	....	....	....	....	24
30	4.91	3.58	84	92	100	107	113	119	....	....	....	....	....	....	....	....	27
33	5.94	4.48	....	115	125	133	141	149	156	....	....	....	....	....	....	....	33
36	7.07	5.47	....	141	152	163	173	182	191	204	....	....	....	....	....	....	32
39	8.30	6.57	....	....	183	196	208	219	229	245	268	....	....	....	....	....	35
42	9.62	7.76	....	....	216	231	245	258	271	289	316	342	....	....	....	....	38
48	12.57	10.44	....	....	....	311	330	348	365	389	426	460	492	....	....	....	43
54	15.90	13.51	....	....	....	....	427	449	472	503	651	595	636	675	....	....	48
60	19.64	16.98	....	....	....	....	536	565	593	632	692	748	800	848	894	....	54
66	23.76	20.83	....	....	....	....	....	694	728	776	849	918	981	1040	1097	1201	59
72	28.27	25.08	....	....	....	....	....	835	876	934	1023	1105	1181	1253	1320	1447	64
78	33.18	29.73	....	....	....	....	....	....	1038	1107	1212	1310	1400	1485	1565	1715	70
84	38.48	34.76	....	....	....	....	....	....	1214	1294	1418	1531	1637	1736	1830	2005	75
90	44.18	40.19	....	....	....	....	....	....	....	1496	1639	1770	1893	2008	2116	2318	80
96	50.27	46.01	....	....	....	....	....	....	....	1712	1876	2027	2167	2298	2423	2654	86
102	56.75	52.23	....	....	....	....	....	....	....	1944	2130	2300	2459	2609	2750	3012	91
108	63.62	58.83	....	....	....	....	....	....	....	2190	2399	2592	2771	2939	3098	3393	96
114	70.88	65.83	....	....	....	....	....	....	....	....	2685	2900	3100	3288	3466	3797	101
120	78.54	73.22	....	....	....	....	....	....	....	....	2986	3226	3448	3657	3855	4223	107
132	95.03	89.18	....	....	....	....	....	....	....	....	3637	3929	4200	4455	4696	5144	117
144	113.10	106.72	....	....	....	....	....	....	....	....	4352	4701	5026	5331	5618	6155	128

For pounds of coal burned per hour for any given size of chimney, mutliply the figures in the table by 5.

the assumed height and horse-power is calculated by the formula or taken from the table on page 679.

Velocity of Gas in Chimneys.—The velocity of the heated gas, based on the chimney proportions given in the table, may be found from the following data:

A = Lbs. coal per hour = boiler horsepower $\times$ 5;
B = Lbs. gas per lb. coal = say 20 lbs.;
C = Cu. ft. of gas per lb. of gas
= 12.4 $\times$ (temp. of gas + 460) $\div$ 492;
= 25 cu. ft. for 532° F. = 500 cu. ft. per lb. coal;
V = Velocity of gas, feet per second = $A \times B \times C \div$ (Chimney area, sq. ft., $\times$ 3600).

Based on a gas temperature of 532° F., 5 lbs. coal per hour per rated H.P., and 20 lbs. gas per lb. of coal we have

Cu. ft. gas per second per lb. of coal per hour = 0.1389;
" " " " boiler horsepower = 0.6944;

and the velocities in feet per second, based on the effective areas given in the table, corresponding to different heights of chimney are:

Height, feet....	50	60	70	80	90	100	110	125	150	175	200	225	250	300
Veloc.,ft.per sec.	16.3	17.8	19.4	20.7	22.0	23.2	24.3	25.9	28.3	30.6	32.7	34.7	36.6	40.1

Chimneys with Forced Draft.—When natural, or chimney, draft only is used, the function of the chimney is 1, to produce such a difference of pressure, or intensity of draft, between the bottom of the chimney and the ash pit as will cause the flow of the required quantity of air through the grate bars and the fuel bed, and the flow of the gases of combustion through the gas passages, the damper and the breeching; and 2, to convey the gases above the tops of surrounding buildings and to such a height that they will not become a nuisance. With forced draft the fan or blower performs the function of producing the difference of pressure, and the only use of the chimney is that of conveying the gases to a place where they will cause no inconvenience; and in that case the height of the chimney may be much less than that of a chimney for natural draft.

With oil or natural gas for fuel, the resistance of the grates and of the fuel bed is eliminated, and the height of the chimney may be much less than that of one desired for coal firing. When oil or gas is substituted for coal, and the chimney is a high one, it may be necessary to restrict its draft power by a damper or other means,

in order to prevent its creating too great a negative pressure in the furnace and thereby too great an admission of air, which will cause a decrease in efficiency.

Chimneys for Mechanical Stoker Installations with Forced Draft. —The manufacturers of the Taylor stoker publish a series of curves showing the relative heights, diameters and costs of chimneys for Taylor and for natural draft furnaces, from which the figures in the table on the next page are taken. A column has been added showing the number of pounds of coal burned per hour corresponding with the given sizes of natural draft chimneys, according to the author's formula, lbs. coal per hour = $16.65(A - 0.6\sqrt{A})\sqrt{H}$, which gives about 17% greater consumption with the smallest chimney and nearly 30 per cent greater with the largest than is given by the formula from which the curve for natural draft chimneys was derived. This formula is lbs. coal per hour $=12A\sqrt{H}$. As the author's formula and chimney table in the more than thirty years in which they have been extensively used have never been shown to provide insufficient area of chimney for a given coal consumption, but on the contrary have often been criticised as underestimating the quantity of coal that can be burned with a given chimney, this Taylor formula for natural draft must give figures of coal consumption that are far too low. The formula given for the Taylor stoker is lbs. coal per hour = $21.8A\sqrt{H}$. A = area of chimney in sq. ft., H = height in ft. It is not stated how the coefficient 21.8 is derived. A uniform height of 100 ft. is given for chimneys with Taylor stokers. This is of course ample with forced draft, and 50 ft. would usually be sufficient, provided enough pressure of blast is provided beneath the stoker to overcome the resistance of the tuyeres and of the fuel bed, were it not that a taller chimney is needed to carry the gases of combustion far above the roofs of neighboring buildings.

Chimney Table for Oil Fuel. (C. R. Weymouth, Journal A. S. M. E., Oct., 1912)—Conditions: Sea level; atmospheric temperature, 80° F.; draft at chimney side of damper, 0.30 in.; excess air, less than 50%, assumed 50% for calculations of efficiency and chimney dimensions; temperature of gases leaving chimney, 500° F.; boiler efficiency, 73%; actual boiler horse-power, 150 per cent of rated; lbs. gas per actual boiler H.P., 54.6; height of chimney above point of draft measurement, 12 ft. less than tabulated height. When building conditions permit select chimneys of least height in table for minimum cost of chimney. Chimney capacities stated are maximum, for continuous load equally divided on all boilers. For large

SIZES OF CHIMNEYS FOR NATURAL DRAFT AND FOR TAYLOR STOKERS.

Pounds Coal burned per Hr. Taylor Formula.	Natural Draft.		Taylor Stoker. Chimney Diam.* Ins.	Cost of Chimney.		Pounds Coal per Hr. Natural Draft. Kent Formula.†
	Height of Chimney. Ft.	Diam. of Chimney. Ins.		Natural Draft.	Taylor Stoker.	
2,000	93	56	41	$2,600	$2,000	2,350
4,000	124	74	58	4,600	2,900	4,930
6,000	145	87	70	6,300	3,500	7,500
8,000	162	98	82	7,900	4,100	10,180
10,000	177	107	92	9,500	4,600	12,'780
12,000	190	116	101	11,000	5,000	15,380
14,000	204	124	109	12,500	5,400	18,630
16,000	215	130	117	14,000	5,800	21,100
18,000	226	136	124	15,500	6,200	23,750
20,000	235	142	131	16,700	6,600	26,470
22,000	244	148	137	18,000	6,900	31,080
24,000	252	153	143	19,300	7,200	33,750
26,000	261	157	149	20,600	7,500	34,750
28,000	269	162	154	21,800	7,800	37,100
30,000	276	166	159	23,000	8,000	39,530
32,000	284	170	164	24,200	8,200	42,090
34,000	291	174	169	25,400	8,400	44,700

* All chimneys, 100 ft. high. † Heights and diameters as in 2d and 3d columns.

CHIMNEY TABLE FOR OIL FUEL.—(C. R. Weymouth.)

Diam. In.	Area. Sq.ft.	Height in Feet above Boiler Room Floor.								
		80	90	100	110	120	130	140	150	160
		Actual Horse-power = 150 Per cent of Rated.								
18	1.77	63	75	84	91	96	101	104	108	110
24	3.14	123	148	166	180	191	201	208	215	221
30	4.91	206	249	280	304	324	340	354	366	377
36	7.07	312	379	427	466	497	523	545	564	581
42	9.62	443	539	609	665	711	749	782	810	830
48	12.57	599	729	827	904	967	1,020	1,070	1,110	1,145
54	15.90	779	951	1,080	1,180	1,270	1,340	1,400	1,460	1,500
60	19.64	985	1,200	1,370	1,500	1,610	1,710	1,790	1,860	1,920
66	23.76	1 220	1,490	1,700	1,860	2,000	2,120	2,220	2,310	2,390
72	28.27	1,470	1,810	2,060	2,260	2,430	2,580	2,710	2,820	2,910
78	33.18	1,750	2,150	2,460	2,710	2,910	3,000	3,250	3,380	3,500
84	38.49	2,060	2,530	2,900	3,190	3,440	3,650	3,840	4,000	4,150
96	50.27	2,750	3,390	3,880	4,290	4,630	4,920	5,180	5,400	5,610
108	63.62	3,550	4,380	5,020	5,550	6,000	6,390	6,730	7,030	7,300
120	78.54	4,440	5,490	6,310	6,990	7,560	8,060	8,490	8,890	9,240
132	95.03	5,450	6,740	7,760	8,600	9,310	9,930	10,500	11,000	11,400
144	113.1	6,550	8,120	9,350	10,400	11,200	12,000	12,700	13,300	13,800
156	132.7	7,760	9,630	11,100	12,300	13,400	14,300	15,100	15,800	16,500
168	153.9	9,060	11,300	13,000	14,400	15,700	16,800	17,700	18,600	19,400
180	176.7	10,500	13,000	15,100	16,700	18,200	19,500	20,600	21,600	22,600

plants or swinging load, reduce capacity 10 to 20%. Breeching 20% in excess of stack area length not exceeding 10 chimney diameters. See second table on page 682.)

In using the above table it must be noted that the conditions upon which it is based are all fairly good. With unskillful handling of oil fuel the excess air is apt to be much more than 50% and the efficiency much less than 73%. In that case the actual horse-power developed by a given size of chimney may be much less than the figure given in the table.

DRAFT OF CHIMNEYS 100 FT. HIGH—OIL FUEL

Temp. of gases entering chimney		300	400	500	600	700
		Net chimney draft, inches of water				
Temp. of outside air	60° F.	0.367	0.460	0.534	0.593	0.642
	80	0.325	0.417	0.490	0.550	0.599
	100	0.284	0.377	0.451	0.510	0.559

The net draft is the theoretical draft due to the difference in weight of atmospheric air and chimney gases at the stated temperatures, multiplied by a coefficient, 0.95, for temperature drop in stack, and by 5/6 as a correction for friction. For high altitudes the draft varies directly as the normal barometer. For other heights than 100 feet (measured above the level of entrance of the gases) the draft varies as the square root of the height.

Regulation of Draft with Variable Loads and Oil Firing. (E. W. Kerr, Bulletin 131 Louisiana State University. Experiments with Oil Burning in Boiler Furnaces).—A stack sufficient to give the draft required for the maximum overload should be supplied. More than this should not be supplied, as it adds to the danger of loss from excess air by careless firemen. In one test, with a small load (75%) and the damper wide open, the lowest efficiency was obtained, the equivalent evaporation being 13.2 lbs. of water per lb. of oil, as compared with 15.8 lbs. with the best possible regulation. This test was made with the openings into the furnace carefully regulated. With a wide open draft door the loss might be much greater. With the considerable losses in efficiency due to excessive draft shown by these tests, it is clear that flue dampers are essential for the best results. Of course, the chimney can be proportioned so as to give the proper draft for the maximum load to be carried, though for rated and under-loads a chimney thus proportioned would give a draft too strong for the best economy and the only possible remedy is to use a flue damper. Since the best boiler efficiency is not only dependent upon the proper air supply but upon proper and regular loading, it is best, as far as possible, to take care of the variations in loads with as few boilers as possible. In other words, instead of reducing slightly the fuel supply to all of the oil burners when the load is reduced, it is better to make the reduction with one or two boilers and never change the others. Such an

arrangement makes it possible to operate the constantly loaded boilers under conditions known to be best. In other words, this does away with much uncertainty. The dampers for these boilers can be set at the proper position, the only damper manipulation required being for the small number of boilers used in handling the variation in load.

Lightning Conductors are usually attached to tall masonry chimneys. The Carl Bajohr L. C. Co., of St. Louis, issues a detailed specification for such conductors, which provides for two conductors placed on opposite sides of the chimney, leading to copper plates placed 15 feet deep in moist earth, each conductor consisting of a copper cable of 315,000 circular mils in cross section. Four points of bronze with platinum covered tips, are carried by ⅝ in. copper rods above the chimney. Special precautions for making the joints and installing the conductors are described.

Chimneys for Dissipating Smoke.—A German invention for dissipating smoke by mixing it with the air surrounding the chimney is described in *Power,* April 2, 1912. The upper part of the chimney, one-fourth to one-third its height is latticed by horizontal channels, shown in cross-section in Fig. 279. Air enters through the slots on the windward side of the chimney, mixes with the smoke and escapes on the opposite side, thus diluting the smoke into a foggy mist.

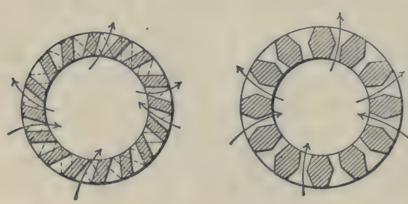


FIG. 279.—DEVICE FOR DISSIPATING SMOKE.

The Design of Breechings and Smoke Flues. (T. A. Marsh, *Industrial Engineering,* Nov. 1912).—Some of the features to be considered in the design of a breeching are:

1. For a given area a circular flue is more desirable than a rectangular flue, due to the fact that the draft loss therein due to friction is less.

2. Sharp bends and angles should be avoided, as these give rise to draft losses of a considerable magnitude.

3. Underground flues are undesirable from two standpoints, namely, inaccessibility for cleaning, and draft losses due to temperature drop in those cases where water can accumulate in the bottom of such flues.

4. Opposing currents of gases should not be allowed to meet, but a deflector should be provided to direct the gas currents in the proper direction.

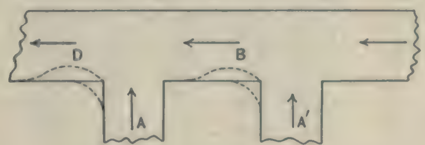
5. The cross-section of a flue should not be suddenly increased or decreased in area, as the result is a marked draft loss.

6. Steel breechings are more desirable than those of brick or cement, due to less draft loss, but for the best results all steel breechings should be covered to prevent radiation and air infiltration.

A common design of breeching is shown in No. 1. This represents

a length of breeching into which the uptakes of several boilers discharge. The connections are usually made without any provision for the entrance of the gases into the main breeching other than at right angles. The result of this is that the gases entering from the uptake *A* have a tendency to cut across the main breeching before their direction is changed. The result of this is a restriction of the area *D*, resulting in an eddy at this point and a virtual reduction of the breeching area from this cause. In case breeching *A* is being worked to its full capacity, this reduction of effective area is considerable and the draft loss at the point *B* is noticeable. The

No. 1.



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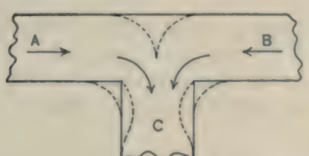

No. 3.

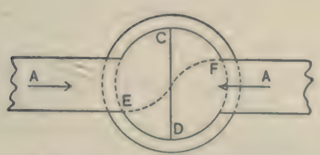

FIG. 280.—DESIGNS OF BREECHINGS.

correction of this difficulty lies in the design of the breeching at the point *C* so that the gases will enter the breeching *B* in somewhat nearly the same direction of flow.

No. 2 is the usual style of breeching used to serve boilers on both sides of a chimney with the chimney out of line with the breeching. The result is the T-shaped design shown. The gases from the side *B* meet the gases from the side *A* in head-on collision causing a reduction in draft pressure. Such a design often results in a draft loss of 0.25 in. of water. The correction for this design is effected by inserting long radius bends as shown in dotted lines on the figure. A curved deflector as shown in dotted outline might also prove to be beneficial.

No. 3 represents the placing of a baffle in the base of a chimney to prevent the gases from opposing breechings meeting in head-on collision. The preferable design of a chimney baffle, however, is

curved as shown by the dotted line *E-F*. This construction results in but a slight draft loss at this point, the gases being gradually diverted and caused to turn upward in a spiral path.

Breeching areas should be designed, not as some function of grate surface served, but to accommodate a given volume of gas at a limited velocity. This volume of gas is determined from the amount of coal

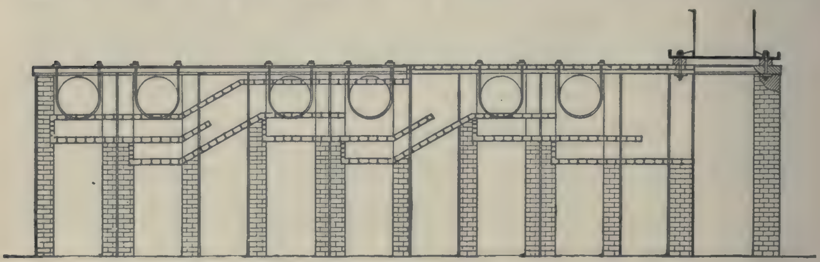

FIG. 281.—STACK CONNECTION FOR SIX BOILERS.

to be burned in order to obtain the desired boiler ratings, and from the amount of air used per pound of coal. A safe rule for gas velocity in breechings is to so design that 35 ft. per second shall be the limiting figure. Beyond this figure, draft losses due to friction soon become excessive.

Fig. 281 shows a stack connection for six water-tube boilers designed by John L. Gill, Jr., in 1892. The right-hand boiler of each

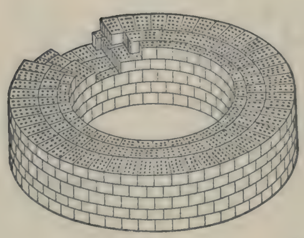

FIG. 282.—RADIAL BRICK CHIMNEYS.

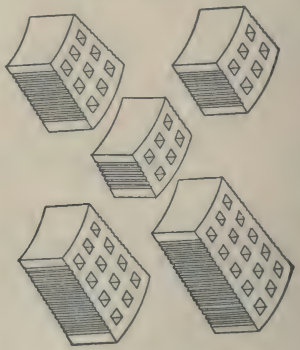

FIG. 283.—RADIAL BRICK.

battery discharges its gas into the lower one of the two flues shown below the drum. By this arrangement the stream of gas from any one does not tend to obstruct the stream from any other, and the draft is thus equalized for all the boilers.

Radial Brick Chimneys.—Fig. 282 shows a portion of a chimney built of special shapes of brick, shown in Fig. 283. By the use of

these brick chimneys may be built much more cheaply than by the use of ordinary rectangular brick, and the old style of chimney is now now longer in fashion. They have been extensively introduced since about 1900. A more recent form of chimney is made of reinforced concrete as shown below.

Specifications for Concrete Chimneys.—Following are extracts from the specifications of the General Concrete Construction Co., Chicago. Fig. 284 gives an idea of the method of construction.

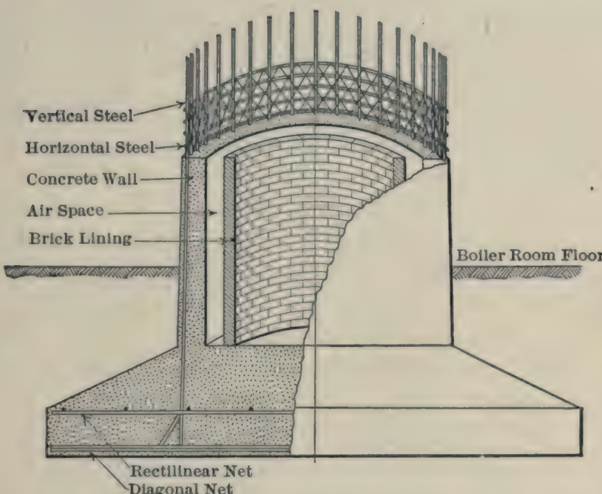

FIG. 284.—CONSTRUCTION OF A CONCRETE CHIMNEY.

Reinforcement.—The foundation will be reinforced with two nets of $\frac{3}{4}$-in. square twisted steel; the lower net placed diagonally and steel spaced 12 in. centers; the upper net placed parallel to sides, steel spaced 24 in. centers. The vertical reinforcement in the chimney will consist of $\frac{3}{4}$-in. square twisted steel; sufficient bars will be used to absorb all tension without stressing it beyond 16,000 lbs. per sq. in. Rods will be uniformly spaced, and placed 3 ins. from the outer surface of the concrete. Joints will lap 30 ins. The vertical rods will be embedded in the foundation and bent under foundation steel for anchorage. The horizontal reinforcement will be a steel net consisting of $\frac{1}{4}$-in. longitudinal rods spaced 4 in. centers, triangularly laced, the ends lapping 6 ins. This net will be placed around and wired at intervals to vertical steel.

Concrete.—The concrete in the foundation will be mixed in the proportion of 1 part Portland cement, 3 parts clean sand and 6 parts crushed stone or gravel. The concrete in the chimney will be a "wet mixture" of 1 part Portland cement, $2\frac{1}{2}$ parts clean sand and 3 parts of 1-in. crushed stone or gravel.

Lining.—The lining will consist of a good grade of hard burned brick, covered with a concrete cap, and separated from the concrete shell by an insulating air space.

Design and Guarantee.—The foundation will be of such size that the resultant of forces will fall within the middle third, and the maximum compression from live and dead load will not exceed the safe bearing value of the soil. The shell at the base of shaft will be of such thickness that the maximum compression on concrete will not exceed 350 lbs. per sq. in. At the smoke opening the thickness of shell will be increased about 30% on each side and extending 5 ft. above and below, and additional reinforcement provided. The chimney will be designed to withstand a wind pressure due to a wind having a velocity of 100 miles an hour and chimney gases not exceeding 1000° F. For a period of five years after completion we will repair free of charge any defects arising from faulty design, defective materials or workmanship.

CHAPTER XIX.

MISCELLANEOUS.

Economizers.—Flue-gas Analyses and the Heat Balance.—Loss of Fuel Due to Keeping Up Steam-pressure in Idle Boilers.—Coal Used in Banked Fires not a Measure of Radiation.—Cost of Coal per Boiler Horse-power per Year.—Boiler-room Labor.—Task Setting for Firemen.—Steam-boiler Practice of the Future.

Economizers.—The Green Economizer, Fig. 285, consists of a rectangular chamber of brick-work filled with a great number of vertical cast-iron water-tubes. The waste heat from the cylinder boilers is carried into this chamber before being allowed to enter the chimney, and heats the feed-water, which passes through the tubes under pressure, to a temperature approaching that of the steam generated in the boiler. This economizer is very commonly used in England with Lancashire boilers, and has been largely introduced in this country, especially in large plants such as sugar refineries. The advisability of its use in any particular case is a matter of close calculation, in which the factors are quantity of coal used and of water evaporated by the boilers, temperature of the feed-water, temperature of the waste gases from the boiler, cost of the economizer, annual cost for interest and probable repairs, and probable saving by the economizer.

Data for Proportioning a Green Economizer.—The Fuel Economizer Co. makes the following statement concerning the amount of heating surface to be provided in an economizer to be used in connection with the given amount of boilers, and concerning the results which may be expected from the economizer:

We have found in practice that by allowing 4 sq. ft. of heating surface per boiler horse-power ($34\frac{1}{2}$ lbs. of water evaporated from and at $212° = 1$ H.P.), we are able to raise the feed-water 60° for every 100° reduction in the temperature, entering the economizer with gases from 450° to 600°.

With temperature entering the economizer at 600° to 700° we have allowed a heating surface of $4\frac{1}{2}$ to 5 sq. ft. of heating surface per boiler horse-power, and for every 100° reduction of gases we have obtained about 65° rise in temperature of the water; the temperature of the feed-water entering averaging from 60° to 120°.

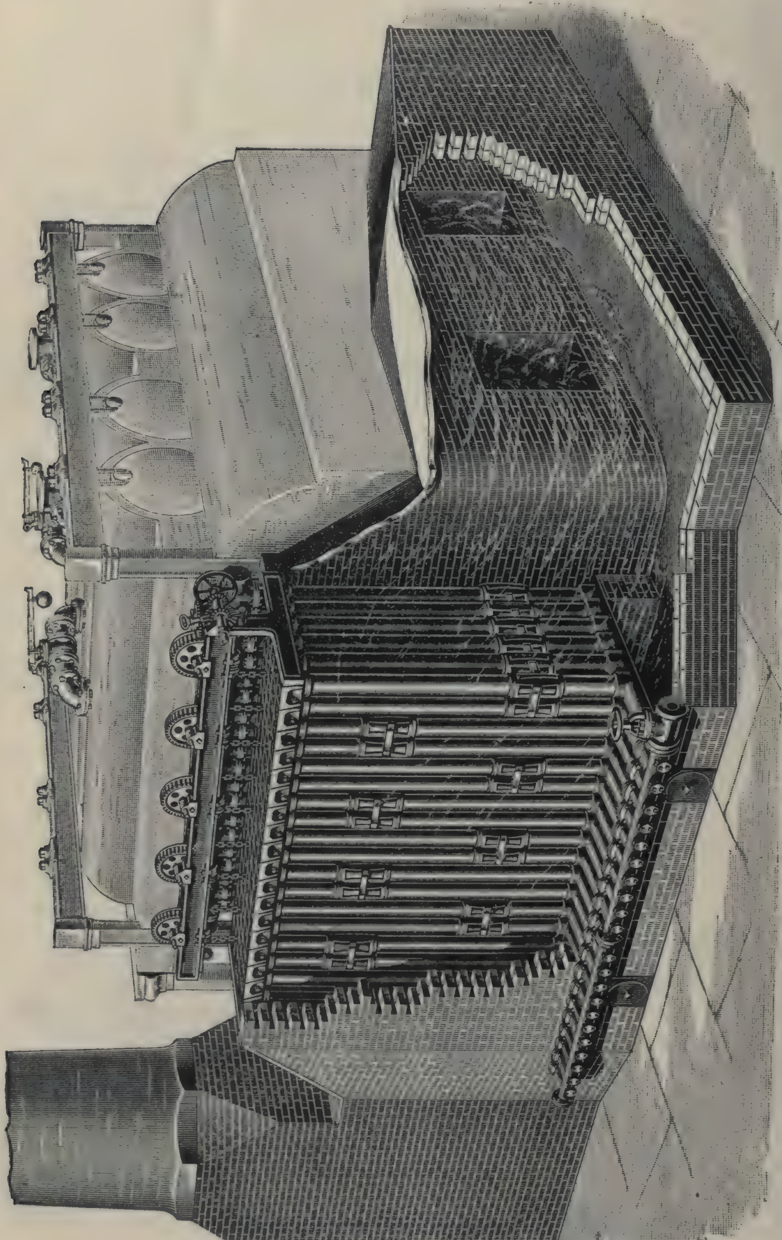

Fig. 285.—The Green Economizer.

With 5000 sq. ft. of boiler heating surface (plain cylinder boilers) developing 1000 H.P., we should recommend using 5 sq. ft. of economizer heating surface per boiler H.P., or an economizer of about 500 tubes, and it should heat the feed-water about 300°.

Calculation of the Saving Effected by an Economizer.—If there were no loss by radiation from the economizer, and no leakage of air into its brick setting, the heat loss by the gases in passing through it, as measured by their difference in temperature on entering and leaving, would exactly equal the heat added to the feed-water. The usual method of calculating the saving of fuel by an economizer when the boiler and the economizer are tested together as a unit is by the formula $(H_1 - h) \div (H_2 - h)$, in which h is the total heat above 32° of 1 lb. of water entering, H_1 the total heat of 1 lb. of water leaving the economizer, and H_2 the total heat above 32° of 1 lb. of steam at the boiler pressure. If $h = 100$, $H_1 = 210$, $H_2 = 1200$, then the saving according to the formula is $(210 - 100) \div 1100 = 10\%$. This is correct if the saving is defined as the ratio of the heat absorbed by the economizer to the total heat absorbed by the boiler and economizer together, but it is not correct if the saving is defined as the saving of fuel made by running the combined unit as compared with running the boiler alone making the same quantity of steam from feed-water at the low temperature, so as to cause the boiler to furnish $H_2 - h$ heat units per lb. instead of $H_2 - H_1$. In this case the boiler is called on to do more work, and in doing it may be overdriven and work with lower efficiency.

In a test made by F. G. Gasche, in Kansas City in 1897, using Missouri coal analyzing moisture 7.58; volatile matter, 36.69; fixed carbon, 35.02; ash, 15.69; sulphur 5.12, he obtained an evaporation of 5.17 lbs. from and at 212° per lb. of coal with the boiler alone, and when the boiler and economizer were tested together the equivalent evaporation credited to the boiler was 5.55, to the economizer 0.72, and to the combined unit 6.27, the saving by the combined unit as compared with the boiler alone being $(6.27 - 5.17) \div 6.27 = 17.5\%$, while the saving of heat shown by the economizer in the combined test is only $(6.27 - 5.55) \div 6.27 = 11.5\%$.

The maximum saving of fuel which may be made by the use of an economizer when attached to boilers that are working with reasonable economy is about 15%. Take the case of a condensing engine using steam of 125 lbs. gauge pressure, and with a hot-well or feed-water temperature of 100° F. The economizer may be

expected under the best conditions to raise this temperature about 170°, or to 270°. Then $h = 68$, $H_1 = 239$, $H_2 = 1190$. $(H_1 - h) \div (H_2 - h) = 171 \div 1122 = 15.24\%$.

If the boilers are not working with fair economy on account of being overdriven, then the saving made by the addition of an economizer may be much greater.

The amount of saving of fuel that may be made by an economizer varies greatly according to the conditions of operation. With a given quantity of chimney gases to be passed through it, its economy will be greater (1) the higher the temperature of these gases; (2) the lower the temperature of the water fed into it; and (3) the greater the amount of its heating surface. From (1) it is seen that an economizer will save more fuel if added to a boiler that is overdriven than if added to one driven at a nominal rate. From (2) it appears that less saving can be expected from an economizer in a power plant in which the feed-water is heated by exhaust steam from auxiliary engines than when the feed-water entering it is taken directly from the condenser hot-well. The amount of heating surface that should be used in any given case depends not only on the saving of fuel that may be made, but also on the cost of coal, and on the annual costs of maintenance, including interest, depreciation, etc.

The following table shows the theoretical results possibly attainable from economizers under the conditions specified. It is assumed that the coal has a heating value of 15,000 B. T. U. per lb. of combustible; that it is completely burned in the furnace at a temperature of 2500° F.; that the boiler gives efficiencies ranging from 60 to 75 per cent according to the rate of driving; and that sufficient economizer surface is provided to reduce the temperature of the gases in all cases to 300° F. Assuming the specific heat of the gases to be constant, and neglecting the loss of heat by radiation, the temperature of the gases leaving the boiler and entering the economizer is directly proportional to (100 — % of boiler efficiency), and the combined efficiency of boiler and economizer is $(2500 - 300) \div 2500 = 88$ per cent, which corresponds to an evaporation of $(15{,}000 \div 970) \times 0.88 = 13.608$ lbs. from and at 212° per lb. of combustible; or assuming the feed-water enters the economizer at 100° F. and the boiler makes steam of 150 lbs. absolute pressure, to an evaporation of 11.729 lbs. under these conditions. Dividing this figure into the number of heat units utilized by the economizer per pound of combustible gives the heat units added to the water, from which, by reference to a

steam table, the temperature may be found. With these data we obtain the results given in the table below:

Boiler Efficiency, Per Cent.	60	65	70	75
B.T.U. absorbed by boiler per lb. combustible	9000	9750	10500	11250
B.T.U. in chimney gases leaving boiler	6000	5250	4500	3750
Estimated temp. of gases leaving boiler	1000°	875°	750°	625°
Estimated temp. of gases leaving economizer	300°	300°	300°	300°
B.T.U. saved by economizer	4200	3450	2700	1950
Efficiency gained by economizer, %	28	23	18	13
Equivalent water evap. per lb. comb. in boiler	9.278	10.051	10.824	11.598
B.T.U. saved by econ. equivalent to evap. of lbs.	4.330	3.557	2.884	2.010
Temp. of water leaving economizer	448°	389°	327°	265°
Efficiency of economizer, %	70	65.7	60	52

Equation of the Economizer.—Let W = lbs. of water evaporated by the boiler, under actual condition of feed-water temperature and steam pressure, per lb. of combustible; G = lbs. of flue-gas per lb. combustible; T_1 and T_2 = temperatures of gas entering and leaving the economizer; t_1 and t_2 = temperatures of water entering and leaving the economizer; then assuming no loss by radiation and leakage, and taking the specific heat of the gas at 0.24 and that of the water at 1,

$$t_2 - t_1 = \frac{0.24G}{W}(T_1 - T_2) = F(T_1 - T_2),$$

in which F has the values in the following table for given values of W and G.

$W=$	8	9	10	11	12
	$F=0.24\ G/W$.				
$G=18$	0.54	0.48	0.43	0.39	0.36
21	0.63	0.56	0.50	0.46	0.42
24	0.72	0.64	0.58	0.52	0.48
27	0.81	0.72	0.65	0.59	0.54
30	0.90	0.80	0.72	0.65	0.60

T_1 is usually fixed by the operating conditions of the boiler, and t_1 by the condenser and feed-water heater conditions.

Taking T_1 at 800, 700 and 600°, corresponding values of F at 0.43, 0.39 and 0.36, and $t_1 = 100°$,

$t_1 - 100 = 0.43(800 - T_2)$; let $T_2 = 300$, then $t_2 = 0.43(500) + 100 = 315°$.
$0.39(700 - T_2)$; 250, $0.39(450) + 100 = 266°$.
$0.36(600 - T_2)$; 220, $0.36(380) + 100 = 237°$.

The mean temperature difference between the flue gas and the water,

$$t_m = \frac{T_1 + T_2}{2} - \frac{t_2 + t_1}{2} = \frac{T_1 - t_2 + T_2 - t_1}{2}.$$

For the three cases given $t_m = 343°, 292°, 242°$.

If $w =$ lbs. of water heated by the economizer per hour from t_1 to t_2, $S =$ sq. ft. of economizer surface, and $C =$ heat units transmitted per square foot of surface per hour per degree of mean temperature difference, then $w(t_2 - t_1) = SCt_m$. The value of C is given by manufacturers as ranging between 2 and 4 for different conditions of practice. It probably increases in some proportion to the increase of t_m, but no records of experiments have been published from which the law of this increase may be determined.

Heat Transmission in Economizers. Carl S. Dow, *Indust. Eng'g,* April, 1909.)—The rate of heat transmission (C) per sq. ft. per hour per degree of difference between the average temperatures of the gases and the water passing through the economizer varies with the mean temperature of the gas about as follows: Gas, 600°, $C = 3.25$; gas 500°, $C = 3$; gas 400°, $C = 2.75$; gas 300°, $C = 2.25$.

Test of a Large Economizer. (R. D. Tomlinson, *Power,* Feb., 1904.)—Two tests were made of one of the sixteen Green economizers at the 74th St. Station of the Rapid Transit Railway, New York City. Four 520-H.P. B. & W. boilers were connected to the economizer. It had 512 tubes, 10 ft. long, 4 9-16 in. external diam.; total heating surface 6760 sq. ft., or 3.25 sq. ft. per rated H.P. of the boilers. Draft area through econ. 3 sq. in. per H.P. The stack for each 16 boilers and four economizers was 280 ft. high, 17 ft. internal diam. The first test was made with the boilers driven at 94% of rating, the second at 113%. The results are given below, the figures of the second test being in parentheses.

Water entering econ. 96° (93.5°); leaving 200° (203.8°); rise 104 (110.3).

Gases entering econ. 548° (603°); leaving 295 (325); drop 253 (278).

Steam, gage pressure, 166 (165). Total B. T. U. per lb. from feed temp. 1132 (1134).

Saving of heat by economizer, per cent, 9.17 (9.73).

Reduction of draft in passing through econ., in. of water, 0.16 (0.23).

Results from Seven Tests of Sturtevant Economizers (Catalogue of B. F. Sturtevant Co.)

Plants Tested.	Gases Entering. Deg. F.	Gases Leaving. Deg. F.	Water Entering. Deg. F.	Water Leaving. Deg. F.	Increase in Temperature.
1	650	275	180	340	160
2	575	290	160	320	160
3	470	230	130	260	130
4	500	240	110	230	120
5	460	200	90	230	140
6	440	220	120	236	116
7	525	225	180	320	140

When to Install a Fuel Economizer. (E. Brown, *Power,* Dec. 17, 1912).—Assuming a 1000-H.P. boiler plant, 150-lb. steam pressure, temperature of escaping gases 600° F., feed water entering the economizer 150°, increase of temperature by passing through the economizer 100°, the calculated saving of fuel by using the economizer is 9.35%. Taking 4 lbs. of coal per boiler horse-power per hour and 7200 hours running time per year, the saving of coal figures up to 1350 tons per year; this multiplied by the cost of coal per ton gives the gross annual saving in dollars.

From this saving must be deducted all charges incident to the operation of the economizer as well as interest on the investment. Under ordinary conditions a good economizer can be installed for about $6.50 per horse-power. This figure includes the apparatus itself, foundations, piping, flues and the increased height of stack necessary, or an induced draft system.

These charges may be tabulated as follows:

Interest on investment	5 per cent
Depreciation (assuming life of apparatus to be 20 years)	5 per cent
Repairs and maintenance	2 per cent
Attendance	2 per cent
Power for operating scrapers and increased pumping head due to economizer	3 per cent
Miscellaneous	2 per cent
Total	19 per cent

On an investment, therefore, of $6500, the estimated cost of 1000-H.P. of economizer, the total charges would be $1235, which must be deducted from the gross saving of 1350 tons of coal. Assuming that coal can be obtained for $1 per ton, the gross saving would be

$1350 from which must be deducted $1235, thus leaving a net saving of $115, which is only 1.77%, but a saving of $1350 additional would be made for each dollar per ton increase in the price of coal.

Explosions of Economizers.—Explosions of economizers are rare, but their possibility should be recognized and guarded against. They may occur from overpressure, due to closing of the outlet valve or other causes, which may be prevented by means of a safety valve. When the gas inlet damper is closed there is a possibility that it may leak combustible gas into the economizer flue, making an explosive mixture which might be ignited by a lighted torch. The headers or tubes may be weakened by internal or external corrosion, and a rupture might occur at the normal working pressure. This should be guarded against by annual inspection and hydraulic test at 50 per cent in excess of the working pressure.

The "Unaccounted for Loss" in the Heat-balance.—In the heat-balance computed from the results of a boiler-test—see Chapter XIV, pages 575 and 581—the heat which is "unaccounted for" sometimes amounts to quite a large percentage of the total heating value of the coal. In one case, with soft coal very high in moisture, the author found it to be more than 20 per cent, even after a liberal allowance had been made for radiation. Some probable causes of this shortage in the heat-balance are the following:

1. The calculations of heat lost in the chimney-gas are based on the supposition that the dry gas contains only CO_2, CO, O, and N. The fact is that for a short period after each firing of fresh coal the gas may also contain H, formed by decomposing the moisture in the coal, and CH_4, distilled from the coal, which are not burned because the furnace conditions were unfavorable. The gas may also contain some SO_2 and NO_2, from the sulphur and the nitrogen in the coal. As much as 1.37 per cent of NO_2 has been found in chimney-gases by Dr. A. H. Gill.* This would indicate the possibility that a small quantity of oxides of nitrogen may be produced from the nitrogen of the air in the boiler-furnace, or from the nitrogen in the coal.

2. The gas analyzed may not be a fair average sample of the gas in the flue. The constitution of gas produced in an ordinary furnace is constantly varying; within a space of ten minutes it may vary from low CO_2, high CO, and no O, through high CO_2, no CO, and low O, to low CO_2, no CO, and high O. The gas is also apt to vary in composition in different parts of the flue. See "Sampling Flue-gases," page 588.

3. The analysis for CO_2, CO, O, and N (by difference) may be erroneous. Sometimes analyses are published which show the total of CO_2, CO, and O to be only about 16 per cent. It is very improb-

* *Engineering News*, Feb. 18, 1897, p. 107.

able that the sum of these gases can ever be as low as 16 per cent in boiler practice, except possibly for a minute or so after firing fresh coal, when large volumes of H and of CH_4 may be given off. When carbon is thoroughly burned to CO_2, either with or without excess of air the sum of CO_2 and O should equal 20.9 per cent, and the N 79.1 of the volume of the gases. Carbon burned to CO only, without excess of air would give a gas containing 34.5 per cent CO and 65.5 per cent N. Hydrogen burned in air without excess would give a dry gas of 100 per cent N. The normal value of the sum of CO_2 and O being 20.9 per cent, and the production of CO by imperfect combustion tending to make the sum of CO_2, CO, and O higher than this figure, it would require the burning of a large percentage of hydrogen, or the dilution of the gas by a large volume of hydrocarbons, to reduce the sum of CO_2, CO, and O to as low a figure as 16. If the sum is below 19, an error in the analysis may be suspected.

4. With some kinds of coal, especially semi-bituminous, which is easily broken into dust, and a high draft pressure, there may be a considerable loss of coal by its being blown out of the stack. An example of a loss of this kind is seen in the records of test of a locomotive boiler on page 620.

Loss of Fuel Due to Keeping Up Steam-pressure in Idle Boilers.— In a report by F. R. Low to the Committee on Data of the National Electric Light Association (*Electrical World,* June 12, 1897) some statistics were presented showing the amount of coal required to keep up pressure while no steam or water is being taken from the boiler. We quote from the report as follows:

When a boiler is laid off it becomes a drag, the coal used in maintaining the fire in a condition to be started counting for nothing, so far as steam-production is concerned. The engineer of a Philadelphia station on a test found that it required 1200 lbs. of buckwheat coal to keep up a pressure of 125 lbs. on two water-tube boilers, having each 59 sq. ft. of grate surface. This was 0.424 lbs. per sq. ft. of grate surface per hour.

A five-days' test of a horizontal tubular boiler showed a consumption of 0.35 lb. of coal per sq. ft. of grate. Another water-tube boiler in a five-days' test used 0.5 lb. per sq. ft. of grate.

A Lancashire boiler with mechanical stokers used only 0.2 lb. of coal per sq. ft. of grate on a seven-days' test.

Two other water-tube boilers, one on a seven-days' test and the other on a test of several days' duration, used, respectively, 0.7 and 0.5 lb. of coal per sq. ft. of grate.

In each of these cases the boiler was shut off from the main and no steam or water taken from it. The coal was used simply to maintain the pressure. A moderate rate of combustion is 12 lbs. per sq. ft. of grate per hour. Allowing 0.5 as the average consumption while standing, the coal burned by a boiler in this way would be 4.17 per cent of that burned while running at 12 lbs. per sq. ft. of grate for the same length of time.

If a boiler runs sixteen hours a day at an average rate of 12 lbs. of coal per sq. ft. of grate per hour, and stands the other eight with a consumption of 0.5 lb. per sq. ft. of grate per hour, the coal used, while idle, will be 2.04 per cent of the whole. If it runs half the time, the expense in coal, while standing, will be 4.17 per cent of the total amount. The following table gives the percentages for different lengths of running and different rates of combustion:

Hours Running.	Hours Standing.	Percentage of Total Coal Used in Idle Boilers at .5 of a Pound per Square Foot of Grate While Idle.				
		Average Rate Combustion per Square Foot Grate While Running.				
		12	15	18	20	24
23	1	.18	.15	.12	.11	.10
22	2	.38	.30	.25	.23	.19
21	3	.59	.47	.40	.36	.28
20	4	.83	.66	.55	.50	.41
19	5	1.08	.87	.66	.65	.55
18	6	1.37	1.10	.92	.83	.69
17	7	1.69	1.35	1.13	1.02	.85
16	8	2.04	1.63	1.37	1.23	1.03
15	9	2.44	1.92	1.64	1.48	1.23
14	10	2.89	2.33	1.99	1.75	1.44
13	11	3.40	2.73	2.30	2.07	1.70
12	12	4.00	3.23	2.70	2.44	2.04
11	13	4.69	3.79	3.18	2.87	2.40
10	14	5.51	4.46	3.75	3.38	2.83
9	15	6.50	5.26	4.42	4.00	3.35
8	16	7.69	6.25	5.26	4.76	3.85
7	17	9.19	7.41	5.96	5.79	4.87
6	18	11.11	9.09	7.69	6.98	5.88

Coal Used in Banked Fires not a Measure of Loss by Radiation.—The heating value of the coal, used when the boiler is idle, averaging, according to Mr. Low's report, 4.17 per cent of that used when it is in operation and burning 12 lbs. of coal per sq. ft. per hour, is not to be considered a correct measure of the heat lost by radiation, since when the fire is banked or the draft nearly all shut off, the coal consumed is burned with an insufficient supply of air, and therefore develops less than its full heating value. The gases evolved from the smouldering fire, whether burned or unburned, escape into the chimney at about the temperature of the steam in the boiler. The coal burned while the boiler is idle therefore represents the sum of three different heat losses, viz., that due to imperfect combustion, the heat carried into the chimney, and the heat lost by radiation.

Assuming a ratio of heating to grate surface of 40 to 1, a rate of driving of 3 lbs. of water per square foot of heating surface per hour and an evaporation of 8 lbs. of water per pound of coal, gives a rate of combustion of 15 lbs. of coal per square foot of grate per hour, a

fair figure for water-tube boilers with anthracite coal. Taking the consumption per hour with banked fires as 0.5 lb. per square foot of grate, gives 3½ per cent of the hourly coal consumption when running, a figure which covers all the losses of heat due to banking fires. The loss due to radiation should be considerably less than this figure.

Cost of Coal per Boiler Horse-power per Year.—Taking a commercial or boiler horse-power as an evaporation equivalent to 34½ lbs. of water from and at 212° per hour, the evaporation per pound of coal under actual conditions of feed-water temperature and steam-pressure at from 5 to 10 lbs., and the cost of coal per ton of 2240 lbs. at from $1 to $5, we obtain the following figures for cost of coal per horse-power per year of 3600 hours or 12 hours per day for 300 days in the year, and per year of 8760 hours, or 24 hours per day for 365 days.

COST OF COAL PER BOILER HORSE-POWER PER YEAR.

Water Evap. per lb. of Coal.	Coal per Boiler H.P. per hr.	Year of 3600 Hours. Cost of Coal per Ton.					Year of 8760 hours. Cost of Coal per Ton.				
lbs.	lbs.	$1.	$2.	$3.	$4.	$5.	$1.	$2.	$3.	$4.	$5.
10	3.45	5.94	11.09	16.63	22.18	27.72	13.49	26.98	40.48	53.97	67.46
9	3.83	6.16	12.32	18.48	24.64	30.80	14.99	29.98	44.97	59.96	74.96
8	4.31	6.93	13.86	20.79	27.72	34.65	16.86	33.73	50.59	67.46	84.32
7	4.93	7.92	15.84	23.76	31.68	39.60	19.27	38.55	57.82	77.10	96.37
6	5.75	9.24	18.48	27.72	36.96	46.21	22.49	44.97	67.46	89.95	112.43
5	6.90	11.09	22.18	33.27	44.36	55.45	26.98	53.97	80.95	107.94	134.92

Boiler-room Labor.—An investigation made in 1896 for the Steam-users' Association of Boston, Mass., by Mr. R. S. Hale, led to the following conclusions concerning the cost of boiler-room labor:

In plants containing 595 boilers the coal consumption was 8302 tons per week, or 700 tons per boiler per year of 50 weeks. The average cost of boiler-room labor per ton of coal handled was 48 cents, ranging from 26 to 74 cents.

The cost gradually decreases as the size of the plant increases, becoming, however, nearly stationary at 200 tons per week.

The men fire more coal (in the proportion of about 15 per cent) and receive more pay (about 10 per cent) in the plants that run twenty-four hours a day instead of ten hours a day, the result being a cost per ton about 5 per cent less. The difference is not quite so marked when comparing plants burning very large amounts of coal (200 tons a week).

The labor per ton of coal is about 10 per cent less for a steady load than for a variable load of any sort.

Handling coal should cost about 1.6 cents per ton per yard up to five yards, then about 0.1 cent per ton for each additional yard.

Cheap men do as much work as good men, so that the cost of labor is almost always less per ton of coal with cheap men. The quality of the work may not be the same, so that the cost per ton of steam is not necessarily less.

Wages of firemen and work done per man are about the same from Maine to Pennsylvania.

One man (besides night man) can run engine and fire up to about 10 tons per week.

One man (besides engineer and night man) can fire up to about 35 tons per week.

Two men (besides engineer and night man) can fire up to about 55 tons per week.

Three men (besides engineer and night man) can fire up to about 80 tons per week.

These figures assume that the night man does all he can of the banking, cleaning, and starting.

The figures are for average conditions. If the conditions are exceptional, as, for instance, a very long wheel or very variable load, proper allowance should be made.

Mechanical stokers save 30 to 40 per cent of labor in very large plants (over 200 tons per week), 20 to 30 per cent in medium-sized plants (50 to 150 tons per week), and save no labor in small plants.

Handling Coal and Ashes in Large Plants.—Mr. Hale's report gives no data of the cost of handling coal in large modern plants, such as electric-light and power-stations. In the best modern practice the coal received by car or boat is elevated and dumped in large storage-bins under the roof of the boiler-house by means of suitable hoisting and conveying machinery. From the bins it is led down by means of iron pipes and fed by gravity directly into the hoppers of the mechanical stokers. The ashes are dumped from the ash-pits of the several boilers into cars or storage-bins in a tunnel underneath. By such mechanical methods of handling both coal and ashes all shoveling is avoided, and the cost of boiler-room labor per ton of coal may thus be made much less than the lowest figure named in Mr. Hale's report. (See table of labor costs in the Delray station, on page 639.)

Number of Boilers to Operate in a Plant with Variable Load.—In an electric power and lighting plant where the maximum load during a portion of the day may be five or more times the load between 1 and 5 A. M., the question arises how many boilers should be operated

and how many shut down with banked fires at the different periods of the day. By a series of tests of one boiler it may be found what is its range of economical load, and at what low load it will pay to shut it down and transfer its load to other boilers. From these results a computation may be made showing at what total load of the whole plant it will pay to shut down one or more boilers. At the Armour plant at the Union Stock Yards, Chicago, there are 32 375 H.P. boilers. The feed water is continuously recorded by a Venturi meter. A chart was made showing the number of pounds of water evaporated per hour by from 16 to 32 boilers, each running at different percentages of their rated load up to 160%.—(*Power*, March 25, 1913.) From this chart the following table has been made. Having such a chart (or table) for any large boiler plant and knowing the percentage of rating below which a boiler is not economical, an inspection of the chart shows how many boilers should be in service for a given total load so that the average rate of driving should be about that corresponding to the most economical rate.

Number of Boilers in Operation.	PER CENT OF RATED LOAD ON BOILERS								
	60	80	100	110	120	130	140	150	160
	THOUSANDS OF POUNDS OF WATER EVAPORATED PER HOUR.								
16	108	144	180	198	216	234	252	270	288
18	122	162	203	223	243	263	283	304	324
20	135	180	225	248	270	292	315	337	360
22	149	198	248	272	297	322	346	371	396
24	162	216	270	297	324	351	378	405	432
26	176	234	293	322	351	380	409	439	468
28	189	252	315	347	378	409	441	472	504
30	203	270	338	371	405	439	472	506	540
32	216	288	360	396	432	468	504	540	575

Task Setting for Firemen.*—That the high thermal efficiency attained by experts during boiler tests is seldom maintained in everyday practice is due to neglect on the part of the management to:

(*a*) Record the conditions causing the high efficiency during the test.

(*b*) Instruct the men how to regulate these conditions in order to duplicate the test results, and

(*c*) Provide an incentive to the men for striving for the purpose desired by the management or owners.

Also in most instances there is no assurance or proof that the

* From a paper by W. N. Polakov. Jour. A. S. M. E., 1913.

high test efficiency was really the highest attainable. For practical guidance the fireman needs at least three instruments:

(*a*) Indicating steam meter.

(*b*) Draft gage.

(*c*) Indicator for the coördination of the condition of firing with the load carried by the boiler at any moment.

The writer arranges on the dial of the steam flow meter an inside dial, as shown in Fig. 286, with numbers indicating the required thickness of fuel bed corresponding to the number of pounds of steam drawn from the boiler and a third dial with numbers indicating the draft which is necessary and sufficient to supply the required quantity of air for the combustion at a rate called for by the indicated steam demand. Thus, if the pointer shows that steam is flowing from the boiler at the rate of 14,000 lb. per hour, the fireman will know that the thickness of coal on the grates should be about $6\frac{1}{2}$ ins., and the draft about 0.4 in. of water.

Fig. 286.—Firemen's Indicator.

The next information vitally important for the fireman is the frequency at which his furnace must be coaled to keep the fires in best condition. The method adopted by the Italian Navy is most satisfactory, consisting chiefly in bell signaling at intervals in proportion to the load carried by the boilers, which signaling is regulated by clock mechanism connected with a flow meter. For use in a boiler house where a number of batteries are fired independently and it was desirable to eliminate the variations of load among them, a modification of this method was devised to equalize the driving of each furnace. For this purpose the counter of the feedwater weigher, supplying water to the entire boiler house, rings the bell every time a certain number of thousand pounds of water is fed to the boilers, thus giving notice to the firemen that an adequate number of shovelsful must be thrown into each furnace. This number is easily determined since the weight of shovelful of coal is known and the rate of apparent evaporation at the given condition of firing is a constant.

In setting a task for firemen, it remains to be determined what the scope of the task shall be. It devolves upon the management to accumulate the detailed and exact knowledge of the most favorable conditions to attain results and make it possible and desirable for every employee to live up to them. It is for the employee, on the other hand, to create or maintain such conditions as are required in the instructions.

Various schemes used as the basis of task setting for firemen have always created dissatisfaction. Certain of these are as follows:

(*a*) The cost of steam generated was used for the basis of the task, and a premium offered for the reduction of this cost, but as firemen have no control over the purchase of fuel, maintenance of equipment, etc., this task involved the standardizing of conditions of combustion, for which no instruments were provided and no definite standard or aim was set.

(*b*) The high percentage of CO_2 in flue gas was adopted as a task basis for firemen in several plants, but the men were not trained nor were they even shown how to obtain it.

(*c*) A high percentage of CO_2 and low percentage of combustible in the ashes, were factors upon which another attempt was made to specify the firemen's task.

(*d*) A limit on coal consumption as a task for railroad firemen was favored at one time. This idea soon demonstrated its weakness.

The common cause of failure of such schemes has been the desire to make a short cut and jump over preliminary studies, and save the time and trouble of training men in a systematic and thorough manner how to accomplish the task set for them.

Neither ratio of apparent evaporation nor boiler efficiency nor efficiency of combustion alone are anywhere near sufficient for the purpose of judging the efficiency of the work of men.

The writer has devised and introduced a comparatively simple method of obtaining a complete record of firemen's performance and to figure their efficiency. This method, which has been in vogue for over a year at the central station at Warrior Ridge, Pa., requires the following record data:

(*a*) Coal records from store issue tickets and coal passers' reports compiled every eight hours.

(*b*) Heat value of fuel determined by bomb calorimeter and value of coal in B.T.U. known for each coal pocket.

(*c*) Amount of water fed to boiler (banked boilers fed separately) ascertained for the same periods.

(*d*) Temperature of feedwater recorded.

(*e*) Steam pressure recorded.

(*f*) Degrees of superheat recorded.

These data are turned over to the station clerk who proceeds as follows:

(*a*) From a slide rule, he ascertains the factor of evaporation on the basis of absolute boiler pressure, temperature of feed and temperature of superheat.

(*b*) By means of a Day and Zimmermann power-plant log calculator he determines for each watch, or for each man, 1, the actual evaporation ratio; 2, factor of evaporation; 3, equivalent evaporation; 4, efficiency of steam generation; 5, cost of fuel per 1000 lbs. of steam. He then enters the results of computation on the daily power plant report form. The whole procedure takes on the average of 18 minutes

of the clerk's time, for whom, incidentally a specific task is assigned and sufficiently hourly bonus offered for, its fulfilment.

Every case of failure on the part of any fireman to secure on his watch the combined boiler, furnace and grate efficiency of 70 per cent or above is immediately investigated by studies of other records and recording charts of draft, temperature of escaping gases, nature of boiler refuse, etc., and if no reason can be found there, an examination of the physical condition of equipment and apparatus is made. The result of this investigation is recorded on a form for cause of lost bonus.

Then the firemen are informed as to the results of their work before they come back for the next watch, and moreover, while they are proceeding with their work, they have in addition to instruments indicating the condition of firing, continuous information as to results they are accomplishing. This is accomplished by having coal weighing and water metering so balanced that an even number of dumps of feedwater and dumps of coal indicates that the ratio of evaporation (superheat, pressure and feed temperature being as specified), is on the safe side of the requirement.

The record of attainment of the task by firemen, kept from the start of task work in the boiler house at Warrior Ridge, shows steady improvement and better habits of men. While the May record showed only 68.7 per cent efficiency of boiler and grates of the whole plant, the record in July showed the efficiency of 73.1 per cent. The number of day-men falling short on the task is steadily reduced. A departure from the principle of separate man's record proved to be so gratifying, creating as it did an unusually strong team spirit of coöperation, that the writer has never attempted to split the records of two or three men working jointly firing one battery of boilers.

The essential thing is that some element of advantage to the workman be introduced sufficient to overcome actual or imaginary disadvantages believed by the men to exist as a result of the new state of affairs. This advantage takes the form of a sufficiently attractive and generous bonus to be paid for willingness to learn the new way and to continue to observe the instructions.

The man for whom a certain task is assigned must strive to accomplish its aim. First, the man must have a desire; secondly, he must make a choice of ways and means; and thirdly, he must perform necessary actions.

As a rule, the workmen feel that the adoption of a new method will impose an undue strain, but it is comparatively easy to overcome this misconception with the firemen from the fact that greater efficiency means less coal to be shoveled. On the other hand, the new conditions require the men to give their attention to instructions and the indications of the apparatus, which diverts them unpleasantly from chatting at leisure with their fellow workmen. This forms a a more serious obstacle to their quick decision in favor of new routine than anything else.

There must be two bonus limits established, a maximum and a minimum. The maximum should equal the net saving accomplished under given circumstances, the minimum is zero. When the bonus actually paid reaches either of these limits it loses its usefulness since it loses its stimulating effect—with the management if the maximum, and with the men if the minimum. Since in an average boiler house the task results in a 25 per cent saving of the coal bill while the firemen's pay roll is from 10 to 15 per cent of the coal bill, there is a considerable latitude for adjustment of bonus.

The success of attainment of the task is determined by detailed, patient and prolonged training and instructions, and this is the most important function of the management. Additional compensation and exhaustive training are imperative, but they alone are insufficient. The conditions under which the men must work must be so arranged as to insure the fullest preservation of their strength, health, and physical faculties.

In a boiler house the amount of work per man per hour is constant, and cannot be increased without knocking down the efficiency to a ridiculously low figure, but the number of foot-pounds of work can be reduced in an inverse proportion to the increase of efficiency, so that the question of preservation of a man's health eliminates any consideration of overspeeding. The conditions which then remain for consideration are (*a*) temperature of room; (*b*) ventilation (dust and draft); (*c*) lighting; (*d*) drinking water; (*e*) restful seats; and (*f*) sanitary washrooms.

One familiar with the common layout of a power plant cannot over-emphasize the importance of the above conditions to enable the men to live up to their task day in and day out. While engine rooms not infrequently offer pleasant and sanitary surroundings, boiler houses are so built as to make them unbearably cold in winter and uncomfortably hot during the summer; ventilation apparently serves either to fill the lungs with coal dust or to chill the perspiring men after cleaning their fires. Lighting is an unusual luxury, so that after looking into the furnace no man could read his gages or examine anything around the boiler. Good drinking water is rarely provided, and restful seats with backs were never found by the writer in any boiler house.

Steady attention on the part of the fireman is much more important than is generally realized. Physical condition and strength being constant, the boiler efficiency percentage is in an almost direct proportion to the degree of attentiveness of the fireman.

In our experience we adopted in addition to time studies, a careful investigation of fatigue, both mental and physical, and measurements of the vitality of the men affected by various conditions of work and number of working hours per day. No task is reasonable unless the workman can fully regain his loss between quitting time and recommencing work the next day, and during a sufficiently long period of observation a man should be able to gain or at least not lose anything

in his vitality. Observations should cover at least four factors: (*a*) weight of body; (*b*) blood pressure; (*c*) temperature of body; and (*d*) pulse. Finally, the time element in relation to task setting for men, particularly if the work requires a considerable strain, must be settled by examination no less careful than the study of the time rate of driving boilers. When, however, as in the case of firemen, both physical strain and attention are required, it was found that with strong, healthy individuals the limiting factor on number of hours of profitable work is set not by physical exhaustion but by weariness of spirit. *Other conditions being equal, a fireman on a 12-hour watch is found to be about 4.5 per cent less efficient than the same man on an 8-hour shift.*

This time-limiting factor on human efficiency, taken in conjunction with a scientific certainty in determination of the most advantageous thermal efficiency, formed the grounds on which the writer rejected the sliding scale of bonus rate results exceeding the task set by various degrees. The task set must be so little below the most advantageous point that it could be reached with greatest benefit to all concerned, and it is not desirable from economical aspects either to fall short of or considerably to overreach it. Offering extra compensation for

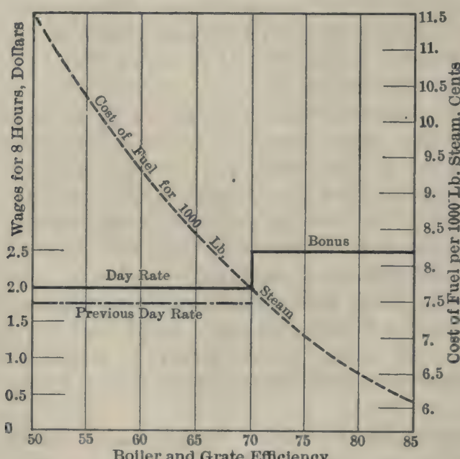

FIG. 287.—RESULTS OF BONUS PAYMENTS.

excess of the task requirement means in final analysis either that the investigator did not determine both limits, or that the management tempts a man to do more than the average employer dares to ask directly.

The example of efficient coöperation between employer and employee in the power plants of public utility corporations here

referred to demonstrated the value of the above principles for setting task and accomplishing the predetermined results in firing boilers.

The diagram in Fig. 287, showing cost per kilowatt-hour of fuel relative to firemen's payroll and bonus before and after adoption of scientific basis for firing, presents, outside of the interesting reduction in cost since the change of method took place, another feature also of no less importance, namely, that since that time the unit cost remained practically constant, while previously it fluctuated considerably.

A Steam-boiler Practice of the Future.—Steam-boiler practice at the present day is in a rather chaotic state. There is a confusing multiplicity of types and of varieties of each type. With any given style of boiler and furnace there is a lack of uniformity in the capacity and economy obtained from boilers of the same size in different places. It is not uncommon to find two or three different styles of boilers in the same boiler-house. In a row of four or five boilers of the same size and style, the arrangement of the flues may differ, so that no two of them have the same draft, and consequently no two of them develop the same power or give the same economy.

Besides the variety in types and in the conditions of running of existing boilers, there is a tendency to change in the conditions. The pressure of steam required by engines is increasing. The small sizes of anthracite are being used instead of the larger sizes, and they require stronger draft, and larger grate surfaces, and give more trouble to handle ashes and clinker. Soft coal is in many places displacing anthracite, bringing with it smoky chimneys, and as the smoke nuisance increases new devices are continually being brought forth to suppress it. Real estate in cities is becoming more costly, and boilers are, therefore, designed to economize space, and they are being driven at more rapid rates. Rapid driving with bad water means more trouble from scale, and this enlarges the business of makers of feed-water purifiers, scale-extracting machinery, and "boiler compounds." This is the age of labor-saving, and in order to reduce the labor cost of steam-making automatic stokers and mechanical means of handling coal and ashes are introduced.

The changes above mentioned are now in progress, but the day when stationary steam-boiler practice shall reach a reasonable degree of uniformity, such as has been reached in locomotives and in marine engines and boilers, seems yet far distant. The fittest will survive at last, but the unfit lives a long time.

The following is a list of the leading types and varieties of boilers which still survive in stationary practice in the United States:

Internally Fired.—Galloway, Scotch marine, locomotive, vertical tubular.

Externally Fired.—Shell boilers: cylinder, two-flue, horizontal, and vertical tubular; water-tube boilers: inclined, vertical, and curved tubes; coil or pipe boilers.

Besides these there are numerous combined and nondescript types, and modifications of standard types, which usually have but a short life in the market.

There is no probability that any increased economy of fuel may be obtained by a change from any one type to another, if the conditions of driving remain the same. With any one of these types an efficiency of from 70 to nearly 80 per cent of the theoretically possible may be obtained from good anthracite or semi-bituminous coal, low in ash and moisture, and burned thoroughly in a properly designed furnace, the boiler being driven at its most economical rate, and proper provision being taken to lessen the losses from radiation and from leaks of air through the boiler-setting. With automatic stokers and with proper adjustment of the air supply, high efficiencies may be obtained at much higher rates of driving than are commonly used with hand firing.

The Survival of a Type will Depend on Some Other Factor than Economy of Fuel.—The possible economy that may be obtained from all types being equal, the standard type or types of the future will be selected for other reasons than economy of fuel. Chief among these reasons are: (1) Safety from explosion. (2) First cost. (3) Durability. (4) Facility for cleaning. (5) Cost of repairs and facility for making them. (6) Space occupied. (7) Possibility of driving at both low and high rates of evaporation without great loss of fuel economy. (8) Adaptability of the boiler and furnace to different kinds of coal, so that the coal may be changed as market prices vary.

The Boiler Types of the Future.—There is not likely to be any important change in the existing types of boiler used in stationary practice, nor is any new type likely to be developed which will offer any advantages over the present types. New boilers or modifications of old ones will continue to be invented, and some of them, by dint of business enterprise and liberal advertising, may be sold in considerable numbers, but the farther these depart in their construction from the existing types the less likely are they to be permanently successful.

The survival of certain types in the struggle between those now on the market will depend not on economy of fuel, as has already been stated, nor on cheapness of first cost, for as the country increases in wealth, boiler users become more willing to pay fair prices for the best boilers. It will depend chiefly on the factors of durability and facility for cleaning and for repairs. Durability depends largely on the kind of water used in a boiler, and therefore a boiler may survive in New England, where the water is generally of excellent quality, while it may be condemned in many sections of the West, where the water contains large amounts of scale-forming material. The question of economy of space occupied will be an important factor in determining the type of boiler to be used in large plants in cities, where real estate is expensive.

Boiler Furnaces of the Future.—The greatest improvement which is to be made in average boiler practice is the adoption of furnaces for burning soft coal without smoke. In ordinary practice in the Western States an efficiency of 50 per cent or less is not uncommon, with the coal burned in ordinary furnaces. It is quite possible to raise this to 70 or even 80 per cent with automatic stokers, furnaces surrounded by fire-brick, provision for securing the intimate admixture of very hot air with the distilled gases, and controlling the air supply in accordance with the indications of gas analyses. The raising of the efficiency of boilers by these means from 50 per cent to 75 per cent would effect a saving of many millions of dollars per year, and it would at the same time abolish the smoke nuisance.

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